Electrical Engineering

October
1937

Published Monthly by the
American Institute of Electrical Engineers

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Electrical Engineering

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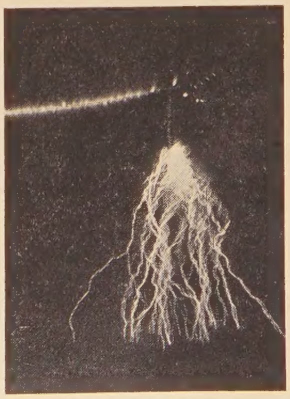
The Cover

A 14-foot discharge at the high-voltage laboratory of the Ohio Brass Company, Barberton, which may be visited by those attending the forthcoming AIEE District meeting at Akron



VOLUME 56 NUMBER 10

Published Monthly by the
American Institute of Electrical Engineers
(Founded 1884)

W. H. Harrison, President

H. H. Henline, National Secretary
G. Ross Henninger, Editor
Floyd A. Lewis, Associate Editor
C. A. Graef, Advertising Manager

Publication Committee—I. Melville Stein, *chairman* J. W. Barker O. W. Eshbach H. H. Henline L. W. W. Morrow A. G. Oehler H. S. Osborne H. S. Phelps D. M. Simmons M. W. Smith W. H. Timbie

Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

High Lights

Spinning Atoms and Electrons. In the construction of the physical world, mass and charge fulfill the rôle of raw materials, and laws of angular momentum furnish the principles of the architecture thereof, according to a noted authority who recently discussed the subject at a meeting of the Institute's New York Section (*pages 1228–35*).

Out-of-Step Protection. Relay requirements for the protection of machines operating out of step may be determined by geometric treatment, which reveals that the common method of assuming a system to be pure reactance leads to errors in low-frequency systems that have low reactance (*pages 1261–7*).

Radio Interference. Radiobroadcast listeners today demand reception free from interfering noises, while the variety of devices that may produce noise increases continually; co-operation between manufacturers and service men, radiobroadcast interests, and public utilities may bring interference under control (*pages 1248–52*).

Alternator Currents. By the application of symmetrical components, armature and field currents of an alternator under unsymmetrical short-circuit conditions may be obtained that agree well with oscillograms; the method aids in the determination of the effect of resistance in armature and field circuits (*pages 1268–76*).

Lightning. Laboratory tests with the lightning-stroke generator and field observations have given information on the lightning-stroke channel; the results suggest a pressure in the "core" some 40 to 60 times atmospheric pressure and a corresponding gas temperature in the range of 11,000 to 17,000 degrees Kelvin (*pages 1253–60*).

Protective Multiple Earthing. Investigation in England shows that the present methods of earthing (or grounding) rural electric circuits are not wholly adequate for all circuits; recommendations for improving the situation have been made (*pages 1245–7*).

Letters to the Editor. Subjects discussed in the "Letters" columns of this issue include: AIEE Student Branch activities; Institute programs and publications; characteristics of human nature; electric-range units, and solution of impedances in multiple (*pages 1326–9*).

Specialization in Education. "Get the humanities and foundations of science, but don't get technology," say industrial leaders when asked what type of education they want in the engineers they hire (*pages 1238–40*).

Engineering Profession. The method of engineers rather than their occupation is the characteristic of the engineering profession that distinguishes it from other learned professions, according to a well-known past-president of the Institute (*pages 1235–8*).

Adding With the Slide Rule. By combining the ability of the slide rule to perform addition with its more usual functions as a multiplying device and a set of tables, the usefulness of this familiar device may be greatly extended (*pages 1243–4*).

Engineers and Economics. A noted engineer and educator, past-president of the Institute, has suggested some ways in which engineers may secure greater influence in guiding economic affairs that have an impact on engineering (*pages 1225–7*).

Induction Motor Performance. A method of predicting the performance of single-phase induction motors from design data has been developed which is said to be shorter and more direct than some other methods in common use (*pages 1277–84*).

Pacific Coast Convention. Activities at the Institute's 1937 Pacific Coast Convention held recently at Spokane, Wash., are reported in the news section of this issue; a total of 266 members and guests registered (*pages 1320–2*).

New Photometric Unit. A new unit of candlepower has been adopted by the International Committee on Weights and Measures which it is hoped will be put into use in 1940 (*pages 1323–4*).

New Committee Chairmen. Beginning with this issue, newly appointed chairmen of AIEE committees are being introduced to the membership through the "Personals" columns (*pages 1330–1*).

D-C Machine Tests. Recently developed methods of measuring the stray load loss of d-c machines with consistent results permit more accurate determination of the losses and efficiency (*pages 1285–9*).

Physics in Engineering Education. According to one authority, effective instruction in physics determines the quality and tempo of engineering teaching (*pages 1241–3*).

Government Reorganization. Comments on this subject were included in the current "News Letter" of American Engineering Council (*pages 1325–6*).

DISCUSSIONS

Appearing in this issue are discussions
of the following papers:

Insulation

Oxidation in Insulating Oil—Whitehead and Mauritz 1304
Properties of Saturants for Paper-Insulated Cables—Sommerman 1302
Tests on Oil-Impregnated Paper—II—Race . . 1298
The Dielectric Strength of Noninflammable Synthetic Insulating Oils—Clark 1299

Electrical Machinery

Approximating Potier Reactance—Beckwith . . 1318
Characteristic Constants of Single-Phase Induction Motors—Morrill 1312
End-Winding Inductance of a Synchronous Machine—Caldwell 1312
Reactance of End Connections—Douglas . . . 1315

General Power Applications

A-C Motor Protection—Kuhn 1306
Coincidental Electric Drives—Miller 1307
Impulse Operation of Magnetic Contactors—Stansbury 1307

Insulation Co-ordination

Application of Spill Gaps and Selection of Insulation Levels—Melvin and Pierce 1290
Application of Arresters and the Selection of Insulation Levels—Foote and North 1293
Basic Impulse Insulation Levels—EEI NEMA Joint Committee 1298
Insulation Co-ordination—Sporn and Gross . . 1296
Insulation Strength of Transformers—AIEE Subcommittee 1297

Power Transmission

New Oil-Filled Cable Lines in Chicago—Halperin and Shanklin 1307
System Recovery Voltage Determination by Analytical and A-C Calculating Board Methods—Evans and Monteith 1308

Vibration and Balance

Dynamic Balancing of Small Gyroscope Rotors—Esval and Frische 1305–6
Vibration Isolation of Machinery—Hansel. . . 1306
Vibration-Measuring Instruments—Greentree 1305–6

Statements and opinions given in articles and papers appearing in Electrical Engineering are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ Electrical Engineering is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). ¶ Copyright 1937 by the American Institute of Electrical Engineers. Number of copies this issue—19,700.

Engineers and Economics—II

By DUGALD C. JACKSON
PAST-PRESIDENT AIEE

What is the appropriate attitude for engineers to take toward economic problems, as individuals and through the AIEE? In response to a request from the Institute's publication committee, a noted engineer and educator here gives his answer to that question.

At THE 1937 AIEE summer convention held in Milwaukee, Wis., an informal session was held to discuss, among other subjects, what the Institute might do to aid the thinking of members regarding the engineer and his relation to economics, over which session I was asked to preside. The circumstances lead me to take that session as an example and as text for this article. The session was attended by perhaps 35 of the younger members of the Institute, including those who were in and out. The discussion was lively. It mostly related to what the Institute and its individual members can do to aid in economic controls. Extreme diversity was exhibited in the views individually expressed with full sincerity, which is common in such forums when economic and social problems are discussed. Also several aspects of any problem were likely to be entangled together in confusion by any speaker, which also is usual in such forums. When I speak of "such forums," I mean groups of able and sincere men who have lived through widely different social and economic experiences and who therefore have diverse (and often contradictory) intellectual outlooks which have arisen from their diverse experiences.

In their primary vocations, engineers have a distinguished habit of studying all the facts of a problem in hand, analyzing the problem into its component elements, filling in incomplete premises by judgment founded on experience with previous problems, then solving the problem by logical reasoning from the premises, but always remembering that the synthesis is only an approximation to exact truth because some of the analyzed premises were incomplete as to facts and were filled in through the application of judgment.

Here we have the age-old, sound process of guiding our thinking by our learning. The Chinese philosopher Confucius, nearly 2,500 years ago, admonished his disciples that thinking without learning is dangerous. We engineers habitually avoid the danger in connection with our technical problems by learning all we can relating to analysis and synthesis of each problem and guiding our thinking thereby. Under these conditions, different engineers of broadly competent experiences readily agree upon the relative merits of different solutions for an engineering problem. Sentiment and prejudice have little place for expression in such situations, and wishful thinking without a factual foundation no place whatever. Examples in which associations of engineers have become of recognized influence as voluntary advisers in engineering matters relating to municipal affairs, such as the situation in Milwaukee which was referred to in the session at the AIEE Milwaukee Convention, are instances where the facts have been sedulously studied for each problem and recommendations made after careful analysis to assure that the facts are understood, followed by synthesis of the results into a clear solution. Recommendations based on such a foundation are always persuasive and are likely to be convincing to any unprejudiced mind.

It is difficult, however, to secure facts for such a solution in social affairs which play so large a part in political economy. I use the phrase political economy as a synonym for economics, in the sense of that branch of learning which comprises the physical and financial, i.e., the material, aspects of social organization, as distinguished from the moral and sentimental aspects of human relations which are peculiarly comprised within the fields of religion and philosophy. We thus have for political economy (of which phrase, the word economics is a synonym) a field which is modified by the state of science and invention and by the modes of living which change from generation to generation as a consequence of experience guided by changes of science and invention. It is a big field which includes concretely the various problems discussed at the informal session in Milwaukee, besides many other important problems.

Economists are likely to leave us considerably in the dark regarding the economic aspects of our problems. Moreover much of economic writing is not directly applicable to engineering affairs. Engineering is a branch of learning and practice which bridges the gulf between the physical sciences and political economy. Therefore, it is natural that only a part of the structure of political economy should at present directly affect our engineering affairs, just as only a part of the structure of science directly affects engineering at present. We, therefore, must help ourselves toward understanding the impact of political economy on our engineering affairs, while enlisting

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This is the second in a series of articles on this subject prepared especially for Electrical Enginebring; the first, by Morris E. Leeds (A'01, F'26) was published in the February 1937 issue, pages 206–07.

Dugald C. Jackson is professor emeritus of electrical engineering, Massachusetts Institute of Technology, Cambridge. He received the degree of civil engineer from Pennsylvania State College in 1885 and the honorary degree of doctor of science from Columbia University in 1932. From 1887 to 1891 Doctor Jackson was engaged in the design and construction of electric light and power plants and distribution systems, and in electric railway work. In 1891 he became professor of electrical engineering at the University of Wisconsin, and in 1907 professor and head of the department of electrical engineering at Massachusetts Institute of Technology, which position he held until his retirement in 1935. He was engaged in consulting engineering from 1891 to 1930, and was particularly active in the fields of railway electrification and public utility affairs. In addition to his term as president of the AIEE (1910–11), Doctor Jackson has served on many AIEE committees over a period of more than 20 years, including chairmanship of the following: standards, 1920–21; traction and transportation, 1914–16; education, 1909–10; Edison Medal 1930–32–33; institute policy, 1928–30. He is a member of many other technical societies in this and other countries, and among other honors he has received the Lamme Medal of the Society for the Promotion of Engineering Education, of which society he was president 1905–06. He is the author of 5 books and numerous articles and papers.

the aid of economists in our effort to gain that understanding. This may be carried out in a way that is analogous to the manner in which we have come to understand the impact of science on engineering. As engineers, we continue our intimacy of thought regarding science, and we mutually discuss our problems in the light of science. Our situation calls for a like mental attitude toward political economy.

Those economists who call themselves sociologists are sincerely endeavoring to assemble a factual basis which ultimately may be helpful to our understanding of the relations of engineering to the betterment of life, but the basis is yet so meager that the forward visions of the sociologists are mostly hope, guided by sentiment. As highly as we all regard those 2 qualities (hope and sentiment), we must dismiss the combination from consideration as an adequate foundation for engineering works. Hope guided by science or experience, accompanied by great industry, has led to many great inventions in our field; but this combination of hope guided by science or experience commands infinitely greater reliance than hope guided by sentiment.

The sociologists have produced writings from which we can glean an understanding of the reason why certain types of organizations in the field of engineering are objects of so much popular suspicion and even resentment. For example, the recently published book entitled "American City, a Rank and File History," by Charles R. Walker, with its sordid but unhappily true tale of illegalities and tricky practices exercised or condoned by those least to be justified by standing and education, discloses some of the grounds. However, we must make our interpretations for ourselves rather than accept, second-hand, the interpretations of disciples.

Of this last point, I may be permitted to elaborate an illustration. Karl Marx, of widespread note, author of "Das Kapital" and other widely quoted writings, was a genius in investigating and expounding the philosophy of history, but when dealing with man's daily interests his writings are sometimes contradictory and, it seems to me, are frequently inaccurate. His numerous disciples have interpreted his writings into a structure of the utmost unsoundness, so that such truth as exists in Marx's own philosophy can be grasped only by reading his own productions and considering the groundwork from which his philosophy springs.

There is thus at large much loose talking and much wishful thinking about affairs in the realm of economics which affect us as engineers. Considerable American legislation and some business activities follow the dictates of wishful thinking. We engineers are not altogether without blame. In this realm of economics, which is not a specific part of our own field, we (ourselves) are likely to do thinking and talking without first securing a competent degree of learning regarding the realm and its various features. We go contrary to our usual practice in our engineering specialties. We sometimes take our opinions second-hand, without such critical examination as will assure us that the opinions are founded upon a broad base of facts, and we reach mental decisions without adequate facts for a basis. Leisure is not available for engineers actively employed in their absorbing vocational specialties to follow this collateral path with will and concentration. The results are not in keeping with our repute in the realm of scientific matters. We become imbued with ideas which are only partially supportable. We may come to believe that these ideas are sound "principle," which leads to such reluctance toward modifications that our colleagues with other views may cry "prejudice."

Here again, I may be permitted to illustrate. For some 25 years I lectured on the organization and administration of public service companies as part of my duties as head of the department of electrical engineering at Massachusetts Institute of Technology. This imposed the necessity of discussing corporation forms of organization for such companies. Year by year the students in the group were 15 to 20 graduates of MIT and other engineering schools, and were fairly mature. All had preceded their engineering school undergraduate career by one of the usual forms of preparation for college admission. They were drawn from all parts of the country and many walks of life. They came from the homes of mechanics, industrial managers, bankers, merchants, merchants' clerks, farmers, and so on.

The corporate form of organization (i.e., a corporation) for doing business, established in conformity with specific laws of our several states, is so widely used as an instrumentality of legitimate businesses (large and small) in so wide a range of business activities that obviously it has been accepted by experienced and honest business men as a fair and useful instrument in our social setting. Indeed some who have studied and reflected on the matter believe the corporate form in business to be one of the most serviceable evolutions which have occurred for advancing general welfare. It makes practicable the carrying on of large enterprises which otherwise could not be carried on with equal advantage to the public. It is serviceable in large and small businesses. It operates under legal limitations which can prevent abuses. I confess to being one of those who believe in the desirability of corporations; but I am ready to recognize abuses which arise from the application of defective laws. These abuses can be eradicated on public demand arising for modification of the applicable laws.

In opening the discussion of corporate forms to this group of graduate students I usually asked a few questions to bring out the knowledge which they already possessed respecting corporations and the opinions of the individuals in regard to the corporation as an instrumentality for carrying on business. Year after year without exception a considerable proportion expressed opinions adverse to corporations and often inferred that they were instrumentalities for legalized extortion from customers or other unfair practices. "One sided," do you readers mentally exclaim? But read farther! Now and then there would be in this category of corporation detractors the son of a merchant or of a merchant's employee, proud of the business in which his father was engaged and proud of his father's pride in it, but unknowing that this business, worthy of honest pride, was carried on as a corporation. One sided? I agree; but more—it is an illustration (perhaps somewhat extreme, though true) of our frequent manner when dealing with economic matters of thinking (and talking) without associating the thoughts with proper learning, contrary to Confucius' ancient but excellent admonition and equally contrary to our own habit when dealing with technical affairs.

To show that observation of such an attitude is not an isolated experience of my own, I will quote from a test by the distinguished psychologist E. L. Thorndike. Professor Thorndike in 1934 made a test of the extent of information and quality of reasoning on business and economic issues exhibited by a group of 76 unemployed persons (44 men and 32 women). He says that the group was "much above the average for the United States" in general intelligence and education. Over half this group alleged that no trade can possibly benefit both parties to the trade. Except that such unsound thinking is injurious to our national society, we might view it with the same humorous tolerance as we view the schoolboy's reputed definition of the word "husbandry" to mean "male dominance." Unfortunately the tragedy lying in the wake of economic errors strips them of all humor.

Some of the responses to certain of his test questions appeared to Thorndike "to be symptomatic of a tendency to regard owners of business concerns and traders as being paid too highly for the services which they and their property render." He worked out such things into what he calls a "prejudice score" for the individuals of his group, a high score meaning high prejudice. He sums up by saying that the abler minds in the group have slightly lower prejudice scores, but the differences can be accounted for by the fact that they make fewer errors of all sorts; that the younger individuals show higher prejudices than the older ones and the women show less than the men; also that ability in an academic examination in economics involves but slight decrease in the prejudice. This prejudice (regarding business affairs) is of a peculiar character "being immune to intelligence of the individual and almost immune to academic knowledge of economics." Of course, Thorndike's group was not composed of engineers; but, are we engineers immune from the same typical prejudices? The informal session at Milwaukee showed that in economic affairs we manifestly arrive at diverse conclusions (which we individually stick to as though they represent abstract, right "principle"), all drawn from alleged similar premises. Is not this definite evidence that in economic affairs people (even engineers) are likely to do their thinking without first accumulating adequate learning? Also, may it not demonstrate that emphatic reliance on our individual inferences leads us to forget that the inferences of no single purely human being ever approximated to "abstract principle," and therefore such inferences should be open to criticism and argument without acrimony?

The circumstances being as thus outlined, what can we do to rescue ourselves from so false a situation and thereby secure more influence in guiding economic affairs which have an impact on engineering? Obviously we must improve our thinking, which we may accomplish in several ways, including among others the following procedure:

First: Members of our Sections can promote informal discussion sessions directed toward economic affairs, in which all points of view regarding the particular affairs are sought out and the adequacy of the foundation for each view is frankly discussed, while rancor is suppressed. By such discussions, the causes of divergence of views may often be exposed and correct views mutually reached. Some who enter such discussions may profit by reading the little book by John Morley (the distinguished British Liberal) entitled "On Compromise," which was published many years ago. The Engineers' Council for Professional Development (which is a mutual instrument of 7 great national societies in the engineering field) has as one of its objectives the aim to give aid to the younger engineers in arranging their continuing self-education. Through its headquarters at 33 West 39th Street in New York City advice may be secured regarding the co-operation of sections of other engineering societies in discussion sessions and collateral educational activities. It is important for the welfare of such discussion sessions that the general topic for consideration shall be clearly announced in advance and that the chairman shall hold each speaker to limits within range of the topic. Aside from this, and the rule that each speaker shall assume the sincerity of all other speakers, no discussion rules are needed.

Second: Sections may invite influential men of the community who are men of experience in business affairs to make addresses in exposition of their own views on questions about which differences have arisen in the informal sessions, if such sessions have been held. To gain any effectiveness from this, any guest invited to give the address on a controversial subject should understand that on some other date an equally distinguished man known to have opposing views will be (or has been) heard. Such bilateral exposition in controversial fields by experienced and honest men of diverse views is the only means of gaining real learning in controversial matters where lectures are relied on. For real learning, however, the discussion sessions are preferable. Professional lecturers dealing with this realm should be viewed with caution because they often are either over-dogmatic or superficial in their expressions.

Third: An informal session at each national convention, of character similar to the Milwaukee discussion session and programmed in advance, would bring together views from all parts of the country if there is as much interest in economic questions among the members under 50 years of age as was alleged in Milwaukee. Catch-as-catch-can rules for debate are appropriate for such sessions provided each speaker will respect the sincerity of every other one, and the presiding officer possesses a fund of common sense in restraining the speakers from straying too far from the objective topic which was programmed. After several such occasions we might find (at least in some of our problems) such unity of views founded on adequate grounds that our mutual influence in the nation would become large in relation to economic affairs affecting our particular branch of engineering. At present we have no such joint influence because we do not agree with each other. We have not as yet mutually accumulated the learning sufficient to support and guide that soundness and unity of thinking in economic affairs which is essential for securing an influence in them that is comparable with our influence in specific technical affairs.

Spinning Atoms and Spinning Electrons

An address* describing how it is known that atoms, electrons and other fundamental particles are continually spinning

By K. K. DARROW
ASSOCIATE AIEE

NO DOUBT you are all accustomed to thinking of atoms as objects—very small objects, of course—which are endowed with *weight*. I can say that with perfect safety to an audience of engineers and physicists; but indeed it can be said with safety to any audience—I mean, of course, any audience literate enough to attach any meaning at all to such a word as "atom." It may be that philosophers of the past have imagined weightless atoms—I am not historian enough to deny that, nor to affirm it; but if such have ever been invented, they have remained quite outside the currents of modern thought. For us, weight is a property which we attribute to the atom. Since this is, after all, a professional audience, I will now change over to that other word which many people have such difficulty in distinguishing from "weight": I will say that *mass is a property which we attribute to the atom*. In a way, that is a negative statement. It means that we do not hope to explain mass in terms of something more fundamental; it means that we accept mass as being itself so fundamental that even the elementary particles have it. When I say "elementary particles," I am still referring in part to the atoms, though it is a somewhat careless usage to do so; but I am referring also to electrons both positive and negative, to protons, to alpha-particles, to nuclei—to all the particles, in effect, of which the atoms are built up. Also I ought to include the corpuscles of light, but this lecture will be quite long enough if I leave them almost unmentioned. All of these particles, then, are endowed with mass; each of them has a characteristic mass of its own, which we do not attempt to explain, but which we do try to measure as closely as we can.

There is another property, familiar to you though not to everyone, which we accept as equally fundamental and equally unexplainable with mass: it is *electric charge*. We attribute it also to the elementary particles, though not, it is true, to all of them. We assign it to the electrons, of course, and to protons and alpha-particles and all of the hundreds of nuclei which distinguish the elements and the isotopes thereof from each other. When I say that we "assign" it, I do not for a moment mean that we are doing something arbitrary or untestable. We *know* that these elementary particles are charged, and indeed we have measured their charges. Atoms do normally appear to us uncharged, but we know that that is because the elementary particles of which they in their turn are made up are some of them positive, some of them negative, and the balance normally happening to be perfect. Some particles, the neutrons and the corpuscles of light, seem permanently chargeless; but perhaps some day we shall find it expedient to regard them as groups of smaller particles having charges which balance one another. Apart from these 2 cases, we may say with assurance that whenever we penetrate as far into the fine structure of substance as we are able to go, we find the elementary particles invested with mass and with charge.

And now I arrive at the subject of this talk, the *third* property of the elementary particles: the property which is called "angular momentum," or "spin" for short. Now of course I am speaking as to an audience of physicists, for if this were an audience of laymen it would certainly be frightened by such a term as "angular momentum." This is a misfortune, and perhaps a defect of general education; for angular momentum is about as important as mass or charge, not only on the scale of the elementary particles but also on the scale of the visible world. Think what it would mean if there were no such thing as the conservation of angular momentum! The earth might cease from turning, it might cease from providing us with the regular alternation of day and night, and with our standard of the flow of time; it might even cease from traversing its regular orbit, and fly off into space or fall into the sun. Well, I do not wish to scare you with any such dire imaginings—I only want to remark on the fact that the human race has been acquainted for a very long time indeed with angular momentum as something which is unvarying, imperturbable, incessant; for of all the unvarying and imperturbable and incessant things in the world, the rotation of the earth is the most obvious and the most striking. So striking it is, that you might reasonably expect that all the philosophers and all the physicists of the past would have conferred the property of spin on all the atoms which they have invented. Well, they did not; the notions of the spinning atom, the spinning electron, the spinning nucleus are among the newest in physics. I think that some of the reasons for the delay will be evident later on in this talk, but it remains partly mysterious, at least to me. Looking back on the situation with the well-known advantages of hindsight, I do feel a good deal of surprise that the spinning atom did not make an earlier entry upon the scientific stage. Perhaps some of you will remember hearing the words "vortex atom" and "vortex theory" which used to be so prominent in physics, and will take the spinning atom of today for a lineal descendant of those vortices of old. If this were correct, we could trace back the ancestry of the spinning atom for about 300 years; but I think that it is not correct. The vortices of which Descartes and Malebranche were dreaming 3 centuries ago were more like whirlpools of streaming particles, and the vortices which were imagined by Helmholtz and Lord Kelvin some 50 years ago were also whirlpools, but they were whirls in an idealized continuous frictionless fluid. Let us pause for a moment to notice how the attitude of physicists has altered in these 50 years! Kelvin and Helmholtz began with the idea of an ethereal fluid pervading the whole of space, and valiantly tried to represent the atoms as whirlpools in that fluid; but we have long since discarded that ether, and our spinning atoms and other elementary particles are small delimited rotating bodies voyaging in a void.

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*An address delivered before the AIEE New York Section, May 6, 1937.

K. K. Darrow is research physicist of the Bell Telephone Laboratories, Inc., New York, N. Y. He received the degree of bachelor of science from the University of Chicago in 1911 and doctor of philosophy from that institution in 1917. During 1911 and 1912, he studied at the Universities of Paris and Berlin. Since 1917 Doctor Darrow has been in the employ of the Western Electric Company and Bell Telephone Laboratories. He has been engaged largely in writing on various fields of physics and the allied sciences.

It is not therefore the vortex which I will introduce to you as the ancestor of the spinning atom, but rather the "Amperian whirl" as it still is sometimes called. You remember, of course, how Ampère in 1820 made a very great achievement which for the purposes of this talk I will divide into three. First, he discovered the fact that an electric current flowing in a circuit is equivalent to a magnet. Next, he worked out the mathematical laws whereby, given a current and the circuit in which that current is flowing, we may calculate the strength or the moment of the equivalent magnet. I will write down the formula for the case of a current i, flowing in a plane loop of area A: the magnetic moment of the equivalent magnet, μ, is given thus:

$$\mu = iA/c$$

Here c is a factor of transformation which we are now obliged to employ because we habitually use, in atomic physics especially, a unit-system different from Ampère's. The third part of the great achievement was this: Ampère founded what remains to this day the theory of magnetism, by presuming that *the individual atoms of any magnetizable substance are themselves little magnets*, and that *the atoms are magnets because they have little whirls of current in them.*

This notion—the notion that atoms are magnets, and that they are magnets because they have internal circulating currents—is the true forerunner of our present conception of the spinning atom. It is, however, only a very primitive form of the modern conception, and there is much to be added to it. First of all and above all, there is the question of angular momentum. Is angular momentum an attribute of these whirling intra-atomic currents, or is it not? You may think that the answer to this question is self-evidently "yes!" But remember that for many generations of our forefathers electricity was an *imponderable* fluid. Weber, however, did consider the affirmative answer, and Maxwell even attempted to ask the question of Nature by experiment—vainly, as it turned out. Not till the electron was discovered did the mass of electricity become a prominent part of experience. A moment ago I divided Ampère's achievement into three parts; similarly I wish now to divide the discovery of the electron into three. Those who isolated and identified and measured the electron were proving three things: first, that negative electricity consists of corpuscles of a definite charge, e; second, that these corpuscles have a mass, m; and following from these two, the principle which I have called the third part of the discovery, namely, that an electron revolving in an orbit has an angular momentum.

I will designate angular momentum in general by the letter p, and now I will show you a formula for the ratio of μ to p in an atom in which an electron is running around in an orbit and constituting an Amperian whirl. The formula, like this other one, for μ, is valid for an orbit of any shape, but to get it quickly I will simplify by postulating a circular orbit. The radius of the circle being r, the area A is πr^2; the current around it is equal to the electron-charge e, multiplied by the number of times per second that the electron runs around the orbit; if I denote the velocity of the electron by v, this number is $v/2\pi r$; hence the product iA/c is equal to $evr/2c$. Now the angular momentum p of the electron, as you all know, is mvr; and hence for the ratio I derive:

$$\mu/p = e/2mc$$

which is one of the most important formulas in the whole of atomic physics. You notice that it does not involve in any way the size or shape of the orbit or the frequency with which the electron travels around it. It is the same for any or all of the revolving electrons of any atom of any kind.

Now let us see how this formula may be tested. Imagine a rod of some highly magnetizable metal, iron for instance, and imagine it to be unmagnetized at the start. This means, that at the start the little atomic magnets are pointing at random in all directions; that is to say, the vectors which represent their magnetic moments are pointing every way, and so are the vectors which represent their angular momenta, the latter being parallel to the former. Since these atomic vectors of angular momentum are pointing every way at random, they add up to zero, and the rod as a whole possesses no resultant angular momentum; it is just standing still. Now let the rod be surrounded with a solenoid, and by means of a current in the solenoid let it be magnetized to saturation. Now all the arrows representing magnetic moments are pointing parallel to the axis of the rod. But so are all the arrows representing atomic angular momenta! Their resultant is no longer zero—suddenly there has arisen a *resultant angular momentum*, belonging to the totality of all the atomic magnets, and quite large enough to be detected, instead of being tiny like the angular momentum of an individual atom. Unless our theory is fundamentally wrong somewhere, we should be able to observe this resultant angular momentum.

The experiment is done by hanging the rod vertically from a fine suspension, and sending the magnetizing current through the solenoid. At the instant of the magnetization, the rod turns sharply on its axis, twisting the suspending fiber. Thus it manifests the angular momentum of which I have just been speaking—though I ought to say that what we observe is of the nature of a recoil, or back-kick: when the totality of the little atomic magnets suddenly acquires its resultant angular momentum, the substance of the rod as a whole acquires an equal and opposite amount (so as to keep constant the total amount of angular momentum in the universe) and it is the latter which we detect. The experiment is quite a delicate one, but its technique has been developed to a remarkable degree since it was first attempted twenty years ago by Einstein and de Haas. What we measure is the ratio of the magnetization of the rod-as-a-whole to the angular momentum of the rod-as-a-whole; and this is just the same as the ratio of μ to p for the elementary atomic magnets. There are not many properties of matter of which we can say that the value measured on a large piece of matter is the same as the value for the individual atom; but there are a few, and this is one of them.

Now in giving you the result, let me first emphasize the general principle that here we have evidence of the spinning of elementary particles, and of the interrelation between spinning and magnetism. Next, I give you the numerical result itself. For iron and nearly all of the other ferromagnetic materials, we find:

$$\mu/p = e/mc$$

or *twice* the theoretical value which I quoted a moment ago.

This cannot be explained by assuming any peculiarity of size or shape or frequency of the electron-orbits in the atoms, for as I just said the theoretical formula is independent of all these things. We are obliged to make some more drastic assumption. If I had unlimited time before me, I might sketch the history of our assumption; but as I don't, I will come straight to the present situation. We assume first, that in the iron atoms in the rod the electron-orbits are so oriented with respect to each other that their magnetic moments kill one another off completely. We then assume that every electron has a magnetic moment and an angular momentum of its own, intrinsic to it and inherent in it, and altogether independent of whether or not the electron is revolving in an orbit. Just as the earth has a rotation of its own in addition to its elliptical course around the sun, so we imagine that the electron has a rotation of its own; this rotation has an angular momentum, and with it there is connected a magnetic moment. (You will remember doubtless that the earth also has a magnetic moment, but this is one of the analogies which it is better not to force too far.) When we magnetize the iron rod, it is the *electrons* which we are turning; the vectors which we cause to point all in the same direction are the magnetic moments and the angular momenta which are inherent in the electrons, and the value of their ratio is the value which is characteristic of the "spinning electron," as we call it. Therefore, amplifying the notation a little, I write:

$$\mu/p = g(e/2mc) \begin{cases} g = 1 \text{ for electron-orbits} \\ g = 2 \text{ for spinning electron} \end{cases}$$

and now I leave the spinning electron for a few minutes, in order to turn again to the theory of electrons revolving in their orbits.

You all realized, of course, that when I converted the Amperian whirl of current into an electron running around an orbit, I was adopting the atom-model known by the names of Rutherford and Bohr; for these were the original thinkers who impelled all the rest of us, following in their footsteps, to think of the atom as a positively charged nucleus around which electrons are revolving like planets around the sun. This is an atom-model in which magnetism is inherent—*a Rutherford-Bohr atom is intrinsically a magnet.* Anyone who did not know the history of the model might well assume that it was designed expressly to account for magnetism, and any such person might also quite reasonably assume that all the physicists of the early nineteenth century thought of it simultaneously as soon as the electron was discovered. Well, it was *not* designed expressly to account for magnetism, and most of the physicists of the early nineteenth did *not* think of it—or if they did, they thought of it only to reject it. At that time, the atom-model with the orbital electrons seemed to be disqualified by a very potent reason; for according to the classical electromagnetic theory, an electron revolving in an orbit ought to radiate all of its energy in a very short time and fall into the nucleus. Bohr was the man who overrode this objection. He overrode it, not in order to construct a theory of magnetism in defiance of it, but in order to construct a theory of spectra in defiance of it. This theory has been extraordinarily successful. Our theory of magnetism is hardly more than a by-product of that theory of spectra; and this, in an odd sort of way, enhances its credit. A theory devised expressly for a certain purpose is always less impressive than one which follows incidentally from a successful theory devised for quite another purpose; and the contemporary theory of magnetism is a wonderful example of this latter and more impressive type.

The main element of Bohr's theory of spectra—if one can speak of one element as the main one, which is really not quite proper—is an assumption about the angular momentum of the electron in its orbit or, let me say, the angular momentum p of the electron-orbit. It was assumed that the electron may revolve, without radiating its energy, in any orbit of which the angular momentum is an integer multiple of $h/2\pi$, —h now standing, of course, for the famous quantum-constant of Planck which is the emblem of modern physics. I write this down as follows:

$$p = (1,2,3,4, \ldots)(h/2\pi)$$

Bohr was thinking at first about the hydrogen atom; but hydrogen is an inconvenient example to use in talking about magnetism, and iron is a very complicated case indeed, so I will talk entirely about the sodium atom.

The sodium atom has a nucleus with a charge of $+ 11e$, and 11 electrons circulating in orbits around it. This certainly sounds formidably complex, but it happens—and I shall later remind you of this fact—that the orbits and also the spins of 10 of the electrons are so oriented with respect to one another that their angular momenta and their magnetic moments completely neutralize each other.

I shall therefore ask you to imagine these 10 inner electrons as a sort of cloud. The eleventh electron of the sodium atom—known technically as the "valence" electron—cruises around this system; sometimes it is traveling in an orbit completely outside the cloud, sometimes in an orbit which cuts across the cloud, but never in an orbit which is entirely or even mainly inside the cloud. The 10 inner electrons which constitute the cloud neutralize a part of the force with which the nucleus acts upon the valence-electron; but they make—I repeat—not the slightest contribution to the angular momentum or to the magnetic moment of the atom.

I have given above, the permitted values of the angular momentum of this orbit of the valence-electron. Now I point out that to each of these permitted values of p corresponds a permitted value of the magnetic moment μ, which I obtain by multiplying the former with $e/2mc$:

$$\mu=(1,2,3,4,\ldots)(eh/4\pi mc)$$

However, only one (at most) of these values can be appropriate to the normal state of the sodium atom; all the rest must correspond to abnormal, unusual, or "excited" states. We are going to be interested primarily in the normal state, so we must identify the right one. In the early days of the Bohr theory, the right one was supposed to be the first which I have written down. However, the theory has been greatly remodeled and bettered since those days, with the aid of what is known as "quantum mechanics"; and it now seems quite certain that these lists of the permitted values of p and μ for electron-orbits are both incomplete. I must add to each of them the value *zero*, so that the 2 lists become

$$p=(0,1,2,3,4,\ldots)h/2\pi$$
$$\mu=(0,1,2,3,4,\ldots)eh/4\pi mc$$

Moreover, it is precisely this new value *zero* which belongs to the normal state of the sodium atom. So the theory, in this stage, quite definitely prescribes that the sodium atom in its normal state should have no magnetic moment and no angular momentum. But now let us look at the data.

It would do no good in this connection to make measurements on solid or liquid sodium, for in those "condensed phases" the atoms are crowded so closely together as to be badly distorted. We can, however, experiment on free atoms of sodium, in their normal state, in the way illustrated by figure 1. In the upper portion, A represents an "oven" consisting of a small box heated electrically and containing some liquid sodium which is steadily being vaporized. There is a hole in the wall of the box through which free sodium atoms are steadily shooting in all directions, with the distribution-in-speed which we know from the theory of thermal agitation; and beyond, there is a sequence of diaphragms with slits in them which delimit a straight and narrow beam of these fast-moving atoms. Disregarding what the theory has just said, let us suppose that each of these atoms is a magnet—a bar magnet, with a north pole and a south pole. As they emerge from the oven, these atoms must surely be oriented at random in all directions.

Continuing to look at the upper part of figure 1, we have 2 large magnet-poles, and the beam travels between them, having no trouble with molecules of air as it shoots along, for the whole of this apparatus is enclosed in a highly evacuated tube. It may seem natural to visualize these magnet-poles as the 2 broad flat extremeties of a horseshoe magnet, with a uniform magnetic field pervading all the space between them. Such an arrangement, however, would make the experiment futile. Nothing would happen to any of the atoms, for in the uniform field the north pole of each atomic magnet would be pressed downward just as hard as and no harder than the south pole is drawn upward, and the net force would be zero. The beam would go on unbroadened and undeflected, and make a small spot on the screen S, the spot being just opposite the slits in the diaphragms. Something else must be tried; and what we do—or rather, what Gerlach and Stern did in Hamburg some 14 years ago—is, to shape one of the magnet-poles in the form of a wedge and hollow out the other, so that the field between the two shall no longer be uniform. The lower part of figure 1 represents the cross section of such a pair of pole-pieces. The field-strength is now much greater near the wedge than near the opposite pole-piece, and there is a vertical gradient of field-strength which may be made fairly constant over most of the interspace. Rabi at Columbia achieves the same result more efficiently by peculiar arrangements of current-carrying wires instead of iron magnets.

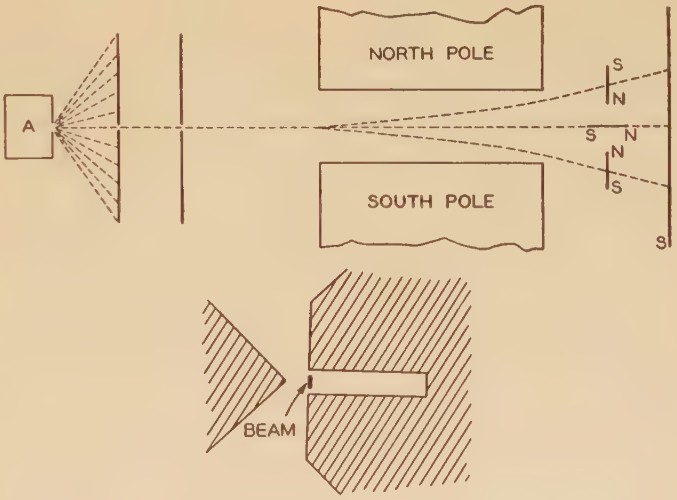

Figure 1. Longitudinal section and cross section of apparatus for the Gerlach-Stern experiment

Now consider (thinking classically!) a few of the atomic magnets as they shoot across this nonuniform field. Think of one which originally is oriented vertically, with north pole down and south pole up—the south pole will be in a stronger part of the field than its mate; it will be drawn upward harder than the north pole is pushed downward; the atom will sweep in a parabolic arc upward. Think of another which originally is oriented vertically with north pole up and south pole down—it will be swept in a parabolic arc downward. Think of another which originally has its axis pointing horizontally—it will shoot in a straight line across the field, as though the pole-pieces were not there.[1] Now think of all those which are oblique to the vertical; they will describe parabolic arcs of intermediate curvatures, upward or downward as the case may be. One infers that the beam must be spread out into a continuous fan, making a continuous vertical band upon the photographic plate.

Moreover, from the upper edge or from the lower edge of this continuous band, it should be possible to determine the magnetic moment μ of the atoms. For let us consider one of the vertically oriented atoms, and call its pole-strength M and the length of its magnet r. The upward force on the north pole is MH, —H standing for the field strength at the point where the north pole is. The downward force on the south pole is $M(H + dH/dz{\cdot}r)$. The net force is $Mr{\cdot}dH/dz$, which is $\mu(dH/dz)$, because Mr is the magnetic moment μ of the magnet by definition. The acceleration of the little atom is equal to this force divided by m_a, the mass of the sodium atom. The deflection is equal to half the acceleration by the square of the time during which the atom is exposed to the force. This time is equal to the distance D which the atoms traverse across the field, divided by v the speed which they have when they come out of the furnace. So finally, we have:

$$\text{Deflection} = \frac{1}{2}\,\frac{\mu(dH/dz)}{m_a}\,(D/v)^2$$

We ascertain the deflection by looking at the end of the band on the photographic plate, and we can ascertain all the other things in the equation excepting μ, —v is the hardest to estimate accurately—and so we can solve the equation for μ.

When the experiment is done there appears, however, a very remarkable thing. Instead of there being a long band upon the plate, there are just 2 spots. Instead of the beam having been broadened out into a continuous fan, it has evidently been split into 2 separate pencils. It looks as though the field had acted first of all upon the magnets, by setting them all vertical—half of them with north pole up, and half with north pole down. Not this phenomenon alone, but many others in nature show us that this is just what happens. You may perhaps feel for the moment that it is intelligible, after all; the compass-needle turns to the north—why should not the little atomic magnets, as soon as they enter the field, turn their south poles toward the north pole of the magnet which attracts them? Well this would not account for the magnets which constitute the beam which bends away from the wedge-shaped north pole, instead of toward it; and indeed it does not even account for the beam which bends toward the wedge-shaped pole. Classically the field should have no orienting effect whatsoever upon the atoms, and yet it evidently does.[1] This is one of the phenomena of the atomic world which we cannot properly visualize in terms of the behavior of objects large enough to be tangible and visible. All that I can do is to assert it, and to say that it justifies us in using this formula to calculate μ. When we use it, the value which we find for the magnetic moment of the sodium atom in its normal state is

$$eh/4\pi mc$$

which happens to be one of the values in the sequence which I just wrote down.

I repeat that according to the theory in its present stage the electron-orbits in the normal sodium atom have a net magnetic moment of zero. This value $eh/4\pi mc$ is, therefore, the magnetic moment due to the spin of the valence-electron—it is the magnetic moment of the spinning electron. I write it in the appropriate place, and then with the aid of the g-value derived from the gyromagnetic effect I write down the value of angular momentum which we assign to the spinning electron:

$$p = {}^1\!/_2(h/2\pi)$$

To this roster of 3 statements about the spinning electron I now make a final addition. The Gerlach-Stern experiment on sodium shows that a beam of sodium atoms—which for this purpose is the equivalent of a beam of spinning electrons—is divided into two by a magnetic field. I write down "2" to indicate this number of separated beams; but I will call it by preference the "number of orientations in the field," because that is the fundamental point. The spinning electron always sets itself in one or the other of 2 orientations, with respect to whatever field it happens to be traversing. We call them the "parallel" and the "antiparallel" orientations, though according to quantum mechanics these terms are a little too strong. Here then is the list of the properties of the electron-spin: g equal to 2—angular momentum equal to $^1/_2(h/2\pi)$magnetic moment equal to $eh/4\pi mc$—2 permitted orientations in any field.

It has doubtless struck you as rather odd that I began by talking about the angular momenta and the magnetic moments of electron-orbits, and then carefully picked out a couple of special cases in which these neutralized each other altogether and there was nothing left over except what I ascribed to the electron-spin. Is there no point at all, then, in talking about the electron-orbits? Oh, very much so! Indeed there are cases in which the electron-spins neutralize each other altogether, and we have nothing left over except what is attributed to the orbits. To do this I may choose an atom like magnesium, which has a nuclear charge of $+12e$, a cloud of 10 inner electrons which neutralize one another completely as to angular momentum and magnetic moment (just as in sodium), and 2 valence electrons instead of one. In some of the states of the magnesium atom—not in all of its states, but in *some* of them—the spins of the 2 valence electrons are oriented opposite to each other in the atom, and cancel each other out. When the atom is in a state of this kind, then nothing is left over except the angular momenta and the magnetic moments of the orbits of the 2 valence-electrons; and then, all the statements of the orbital theory (page 1230) are applicable—g is equal to unity, the angular momentum takes one of the values $nh/2\pi$ and the magnetic moment takes one of the values $n(eh/4\pi mc)$. Moreover, there is another theorem derived from quantum mechanics which turns out to be valid: The number of orientations of such an atom in a field, the number of separated beams which appear in the Gerlach-Stern experiments, is chosen from among the members of this sequence: 1, 3, 5, 7. . . . (It is a most interesting historical fact, that Gerlach and Stern were moved to undertake their difficult experiment by the wish to test this remarkable assertion of quantal theory.) You notice that the number 2 does not appear in the sequence; were it not for the electron-spin, we never could obtain it; it is distinctive of the spinning electron.

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[1] When thinking classically, we must not expect the atomic magnets to turn their axes toward the field-direction as they shoot across the field; the gyroscopic quality of these magnets, due to their angular momentum, inhibits this.

I must, however, admit that all these cases of which I have been speaking are special, and comparatively rare. Both the cases in which the spins neutralize each other perfectly, and the cases in which the orbital moments neutralize each other perfectly—both types are unusual. Still more unusual, and yet occurring here and there, is the most special of all cases—that in which *all* of the moments and *all* the momenta, both those of the spins and those of the orbits, balance one another perfectly so that the sums are zero. An atom in such a state is completely devoid both of magnetism and of spin; such atoms are those of helium, of neon, of argon and the other noble gases, when in their normal states. Usually, however, we find ourselves confronted with some example of the general case, in which neither the spins nor the orbits are completely neutralized. The atom has an angular momentum which is a sort of composite or resultant of the angular momenta of the spins and the orbits, and it has a magnetic moment which also is a sort of composite or resultant.

If I were to embark on the description of the general case this lecture might go on interminably, and at its end you would probably not remember anything except what you had already known at its beginning. The laws of the composition of spins and orbits are so foreign to our customary ways of thinking, and the formulas which express them are so curiously built, that to work once only through them is not sufficient: One has to memorize the derivations and the results alike, and go over them incessantly until they are imprinted on the brain. I think you will agree to this readily enough, when I remind you that this theory is none other than the general theory of spectra; for even quite outside the ranks of physicists, the theory of spectra is beginning to be notorious for its complexity. I shall not venture even to give the formulas, much less their derivations; it must suffice to fill out the 2 lists of p-values and μ-values on which I have already begun, and the list of n-values or numbers-of-permitted-orientations.

The spinning atom is a congeries of electrons, all of them always possessing spin, most of them usually possessing orbital motions; and these motions are compounded with each other in such ways, that:

First, the angular momentum of the spinning atom has one of the values,

$$p = (0, {}^1/_2, 1, {}^3/_2, 2, {}^5/_2, 3 \ldots)h/2\pi$$

Second, the number of beams in the Gerlach-Stern experiment, or the number of permitted orientations of the atom in the field, has one of the values,

$$n = 1, 2, 3, 4, \ldots$$

Third—and now comes a surprise, for you will probably expect me to say of the magnetic moment that it is $eh/4\pi mc$ multiplied either by an interger or a half-integer; but this is not so. The actual state of affairs is described by a formula which is called the g-formula, because it gives g in terms of the moments, both spin and orbit, of the individual electrons. It was discovered by Landé and interpreted in terms of the spinning electron by Goudsmit. The g-formula gives unity, as of course it must, in the special cases where the electron-spins cancel each other and only the orbital moments are left over, and it gives 2 in the special cases where the orbital moments are neutralized with only the spins left over. In the other cases it may give any one of a large variety of values: mostly one gets simple-looking fractions such as ${}^9/_8$ and ${}^4/_3$ and ${}^5/_6$. The magnetic moments are then computed by multiplying the appropriate g-values times $e/2mc$, into the existing values of angular momentum.[2]

I now turn to that component of the atom of which the spin remains to be discussed—to the *nucleus*.

As I have already intimated, the values of p and n and μ for the electron-family of any atom are mostly ascertained by analyzing their spectra and utilizing the great general theory of spectra. Such magnetic experiments as I used for my examples are relatively few, and feasible for relatively few substances. The reason for making this remark at this late moment is, that by analyzing spectra we may also learn something about the spins of nuclei; for nuclei also are invested with these properties of angular momentum and of magnetic moment. I take in particular the case of the *proton*—that lightest of all nuclei, the nucleus of the lightest known kind of atom which is ordinary hydrogen, so called to distinguish it from "heavy" hydrogen. Analysis of the spectrum of hydrogen shows us that the proton is capable of taking 2 permitted orientations in a field; thus, our first piece of information about the proton-spin is conveyed by writing $n = 2$.

Now that we have this piece of information, we deduce that as the spinning electron has an n-value of 2 and an angular momentum of ${}^1/_2(h/2\pi)$, so the proton with its n-value of 2 must have an angular momentum of ${}^1/_2(h/2\pi)$. Continuing along this line of thought, we are further tempted to infer that the proton should have a g-value of 2 and a magnetic moment of $(eh/4\pi mc)$. But what shall we suppose about m? Formerly it represented the mass of the electron; now we are dealing with a different sort of particle, having a mass which (as many other kinds of experiments show us) is about 1,835 times as great as the electron-mass. I denote this mass by M. It seems natural, then, to expect for the magnetic moment of the proton the value $eh/4\pi Mc$, or about ${}^1/_{1,835}$ of that of the spinning electron.

This is a formidably small magnetic moment to hope to measure, nay even to detect! Yet Stern and his pupils undertook to measure it, and they succeeded. Of course, modifications had to be made in the technique which worked so well for sodium. Hydrogen being a gas at room-temperature, no heated oven was required; nevertheless they used an "oven," but it was refrigerated instead of being heated—a sort of super-ice-box; this was in order to obtain slow-moving atoms, for the slower the atoms traverse the field, the more accurately the experiment can be made. I just said "atoms"; but as most people know, the particles of gaseous hydrogen are not atoms, but diatomic molecules—systems composed of 2 protons and 2 electrons apiece. This is a circumstance which in many desirable tests of modern theoretical physics is a great inconvenience, for usually our simplest theoretical affirmations refer to hydrogen atoms and we should like to be able to experiment on them directly. Here, however, it turns out to be a great convenience, indeed perhaps the only thing that makes the experiment possible. For if we had an isolated hydrogen atom, the magnetic moment of its electron would so far exceed that of its proton that the latter would be indetectable. (Perhaps it is not superfluous to mention that bare protons could not be used in the experiment either, as the magnetic field would exert so large a force upon their moving charges that the forces upon their magnetic poles would be insignificant by comparison.)

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[2] Should any reader intend to proceed from this article to a thorough study of atomic theory, he should be warned in advance that according to the latest form of quantal theory, the p-values and the μ-values here given are the values of the projections of these vectors upon the field-direction, the magnitudes of the vectors themselves being somewhat greater: I have given details as to this in "Contemporary Advances in Physics, XXIX, ..." *Bell System Technical Journal,* volume 14, 1935, page 293.

But if in a single hydrogen atom the magnetic moment of the electron swamps that of the proton, how shall this fate be avoided for a system composed of 2 electrons and 2 protons? Here enters in, and in a very important and significant way, that law of the permitted orientations. Just as a spinning particle of angular momentum $^1/_2(h/2\pi)$ can take only 2 permitted orientations in a field, so it can take only 2 with respect to another particle of its kind—the parallel and the antiparallel. It chances—or rather it does not chance, it follows from the underlying laws of nature—that in the hydrogen molecule the 2 electrons are oriented antiparallel to each other. Their magnetic moments cancel each other, and do not trouble the experimenter.

May not, however, the same thing happen in respect to the 2 protons, so rendering the experiment hopeless? It turns out that for these the spins are antiparallel in some molecules but parallel in others. Molecules of the former type, which is called para-hydrogen, are indeed useless for the experiment; but molecules of the latter type, which is called ortho-hydrogen, are available, and in them the magnetic moments of the 2 protons collaborate so that the magnetic moment of the molecule-as-a-whole is twice as great as that of the single proton, a welcome assistance! In ordinary gaseous hydrogen at room temperature, about $^3/_4$ of the molecules are ortho-hydrogen.

When the experiment was at last achieved by the school of Stern, it was found that the foregoing inference as to the μ-value of the proton is roughly but not exactly correct! The latest information is, that the magnetic moment of the proton is close to $2^1/_2$ times $eh/4\pi Mc$. Measurements with another method by Rabi and his school have confirmed these results; and we are definitively debarred from believing that for the proton and the electron, the magnetic moments stand in the inverse ratio of the masses. Perhaps this signifies that the proton is itself a composite particle, a notion for which there is some support from other sources.

I mention briefly the characteristics of a few other nuclei. After the proton, the next simplest is the deuteron or nucleus of the heavy-hydrogen atom. It is composed of a proton and a neutron, the latter being a neutral particle of about the same mass as the proton. We can observe free neutrons wandering about in space, but we cannot determine their spins nor their magnetic moments. The deuteron, however, has 3 permitted orientations (this we discern from the spectrum of heavy hydrogen) and consequently an angular momentum of $(h/2\pi)$. It is inferred that the neutron has $^1/_2(h/2\pi)$ for its angular momentum, and that in the deuteron these 2 constituent particles—proton and neutron—are oriented with their equal spins parallel to one another. The magnetic moment of the deuteron is less than that of the proton, and accordingly the neutron must have its magnetic moment oppositely directed to that of its companion in the system, even though their angular momenta be similarly directed —a strange complication!

After the deuteron, the next simplest among the nuclei (except 2 which are much too rare for investigation) is the alpha-particle or helium nucleus. It is composed of 2 neutrons and 2 protons. We find that its angular momentum and its magnetic moment are zero, a clear indication that the 4 spins of its components are cancelling each other 2 by 2, and the 4 magnetic moments likewise. Next comes a nucleus composed of 3 protons and 3 neutrons, belonging to the element lithium. It is found that in angular momentum as in magnetic moment it is practically a duplicate of the deuteron, its 6 components having disposed themselves into a nearly normal deuteron attached to a nearly normal alpha-particle. I might proceed some distance farther along the list of the known nuclei after this fashion, were there space; but it is best to close this section with a general rule: *nuclei with an even number of constituent particles* (protons and neutrons) *have even spins, nuclei with an odd number of particles have odd spins.* "Even" and "odd" in this formulation mean that the angular momentum is an even or an odd integer multiple of $^1/_2(h/2\pi)$, respectively. One sees that if any 2 spins of magnitude $^1/_2(h/2\pi)$ are allowed to choose only between parallel and antiparallel orientations, the rule follows inevitably; reversely, from the rule (which is based on experience with some 50 or 60 kinds of atom), we derive extra strength for that theorem about orientations.

Now to come to the conclusion and the climax. Although this property of angular momentum, of being allowed to take only a limited number of permitted orientations—although this strange and wonderful property of angular momentum was introduced in this lecture as though it pertained only to atoms subjected to applied external fields, yet it manifests itself far more broadly. Indeed, it manifests itself universally, and the stability and the character of the world are due to it. I have already mentioned in half-a-dozen places how it manifests itself within the molecule and within the atom: how in the atom, it is responsible for those laws of composition which determine the angular momentum and the magnetic moment of the electron-family—how in the hydrogen molecule, it establishes a difference between ortho-hydrogen and para-hydrogen—how in the nucleus it fixes the angular momenta and the magnetic moments of composite nuclei as sharply as those of their constituents the proton and the neutron. Perhaps these seem to be remote and unimportant qualities; but what has just been said of them may be said with equal truth and equal force of *all* the chemical and physical properties of all the elements, mass alone excepted (and even mass not fully excepted). If this feature of angular momentum did not prevail, there could not be the fixity of properties which characterizes each element by itself and the variety of properties which characterizes the totality of the elements. Gold would not be gold, lead would not be lead, oxygen would not be oxygen, helium would not be helium; for though it is commonly said that each element is distinguished by its nuclear charge and the number of electrons in its electron-family, this is not adequate. It is the law governing angular momentum which imprints upon these electron-families the characters which we recognize as the properties distinctive of the elements. It seems strange indeed that character should depend upon motion, and fixity upon the laws of whirling things; but however strange it may seem, there is no doubt about it. In the construction of houses the builder requires raw material in the form of brick and stone and wood and steel; but he requires also principles of architecture, whereby the raw materials may be parceled off and integrated into the general design. In the construction of the physical world, mass and charge fulfill the rôle of raw materials, and the laws of angular momentum furnish the principles of the architecture thereof.

The Engineering Profession

Not what the engineer does, but how he does it differentiates engineering from the other learned professions

By GANO DUNN
PAST-PRESIDENT AIEE

THE ADVENT of the scientific method and the rapid spread of its use in connection with practical things, which began not much more than 150 years ago, called forth the ministrations of many specialists in the application of science to social purposes. There always had been military engineers who made roads, bridges, catapults, and petards; but in the sense we are now considering it, they did not constitute a profession.

To distinguish the new men from these time honored military engineers, they were called civil engineers. In those days civil engineers busied themselves in the whole field of then known science instead of in the narrower field which civil engineering now embraces. James Watt, for instance, was a civil engineer. These civil engineers, as distinguished from military engineers, began to constitute a new class in the community; this class has grown in geometrical ratios as to its numbers and as to the varieties of its occupation, until it has spread its activities into every material department of life. The very foundations of society would be shattered if the class should today cease to exist.

Specialization in this great and growing class has created over 50 branches of engineering sufficiently distinct to be recognized in library catalogs. Because of this growth in scope and subdivision into widely different specialties, occupations in the various engineering branches have become so differentiated that the extremes bear almost no resemblance to each other. Even the grand divisions of the engineering profession represented by the national societies of civil, mining, mechanical, electrical, and chemical engineers, give little more than a hint as to occupation. An electrical engineer may spend his days on the macrocosmic problems of corona in the long-distance transmission of vast amounts of power, or he may wrestle with the microcosmic subtleties of the multiplex modulation of carrier waves. As an indication not only of this diversity of occupation but of the rapidity with which change of subject matter has taken place, I will give a few examples.

It is within my time that power transmission did not

Essential substance of the commencement address delivered at the 70th graduation exercises of the Massachusetts Institute of Technology, Boston, June 8, 1937.

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exist. The electrical engineer of that day, in one group was concerned with the intricacies of direct-current commutation or with the then still unsuccessful endeavor to produce an electric motor that would run on alternating current, which was at that time a novelty limited to the field of electric illumination. In another group he was estimating the economic barrier represented by the cost of 2-wire metallic circuits for telephones, and cogitating whether the priority which telephones shared with the telegraph in the exclusive use of circuits of a single wire with increasingly noisy ground returns was worth the expensive legal fight its preservation was forcing upon him. In another field the coherer was unconscious of the vacuum tube that was to follow.

Mechanical engineers in their sphere burned midnight oil developing a reciprocating steam engine that would run at a speed high enough for the direct driving of electric generators, in order to make possible the elimination of the grave disadvantages of the ubiquitous leather belt. The successful internal combustion engine and a useful steam turbine had not been born.

I could go on, but trust that I have indicated that the progress of the engineering art in the past already has demonstrated the folly of attempting to forecast in the electrical field alone what will occupy the electrical engineer of 150 years hence.

It is possible that I already have gone far enough to have suggested what it actually is that constitutes the practice of the engineering profession and sets it apart from the other learned professions. The answer is: it is not what the engineer does, but how he does it! Not what the engineer's occupation is, but the intellectual processes by which he attacks that occupation.

In other words the method of engineers rather than their occupation is the characteristic of the engineering profession. Method is the common denominator of all engineers. While the *subject matter* of engineering unquestionably will continue to change in the future, not so with the *method* of engineering. It is certain that the engineer of the future will be using the present method 150 years hence, even if no prescience is capable of forecasting to what occupations that method will be applied.

What is this remarkable method that has changed the nature of the world? As is well known, it is the method of science—that process of reasoning based upon observed data and working hypothesis which, by inductive and deductive procedure and experiment, arrives at new knowledge.

It must be pointed out that, except where their qualities are combined, the engineer and the scientist are not the same person, however much they use the same method. Their objectives are different. Many attempts have been made to define engineering, and engineers do not agree on any one definition; but a definition I worked out some years ago seems to stand the test of criticism and of perspective. It is as follows: Engineering is the art of the economic application of science to social purposes.

Being an art, engineering thrives on repetition. It develops skill and it develops style. The second and third power plants that an engineer builds are likely to be better than the first, although there may not have been introduced a single new principle. The scientist, however, shuts his mind as far as possible to all human prejudice and influence of feeling, save only for the divine fire of that imagination which creates the working hypothesis; and he learns how to discern truth and new knowledge in a study of the order of nature.

The engineer, by the same intellectual processes as the scientist, applies that new knowledge to social service. The essential difference between the scientist and the engineer lies in the economic involvement of the engineer's work. In this hot crucible of the economic test all that an engineer does must be tried. To repeat an old saying, an engineer is a man who can do with one dollar what any fool can do with two; and it is in his economic involvement that the engineer can rise to some of his greatest powers.

Economics is a social, not a physical, science. It embraces problems of the human spirit and the behavior of man as man; and because the engineer's art deals with dollars and economic relations, he is bound into the great business structure of society in a way that the scientist is not. Being bound into this structure, he must be a man among men. He must be able to make his views prevail. He must be able to persuade and to contend. He must be able to give blows and to take them. These activities do not devolve upon the scientist in his laboratory. To the engineer, they are everyday life.

If an engineer's training neglects the great human mirrors of history and languages, particularly his own language; if his mind and heart are not sensible to the great social forces of his day and of his community; if he but feebly develops the subtle qualities of character that make for personality, his career as an engineer is limited, no matter how much science he may know.

If the key to the scientist is thought, the key to the engineer is action. Value and utility are the engineer's criteria, rather than truth, which is the criterion of science.

For these reasons, as the engineering profession has developed, the center of education for engineers has been shifting more toward the humanities. This is one reason for the greater part engineers constantly are playing today in the great rôles of life. But while the humanities are of profound and increasingly recognized importance in the arch of an engineer's education, its keystone always will be science.

Not all men with an engineering education take up the practice of engineering. It is significant how many are drawn off into the field of organization and other fields, where the engineering method of approach to problems and the engineering point of view introduce fermenting leaven into many of the processes of traditional business procedure. Partly for this and for other reasons, engineering has become the cornerstone of industry. In the precipitations of relationships brought about by big business and mass production, the function of management has fallen very largely to the engineer.

In the field of management, involving the play of the human spirit at its best and at its worst, where, particularly in labor relations, generosity, loyalty, and independence are manifest as well as passion, ignorance, and vanity, the engineer's capacity for organization, leadership, and sympathy has rare opportunities. Even in these days which we often think to be so far advanced, the sway of prejudice and of certain kinds of superstition is still profound. It awaits the light of reason and human understanding.

Executions for witchcraft were once a common part of everyday life. At the time when Salem shocked the colonies by a series of 19 such executions, literally thousands of witchcraft executions every year were carried out in Europe. Over a period of 40 years there were 8,000 such executions in intelligent Scotland alone. The least unusual circumstance or unexplained phenomenon was liable to be charged to occult and demoniac causes, and constantly brought the penalty of death by flames upon upright and innocent persons or upon individuals who were unpopular or politically inconvenient, or who were merely intellectually independent. This madness, which had spread over most of the civilized world, was dissipated by the same great light that founded the engineering profession. About that time the dawn of the scientific method began to shed its beams of intelligence into the darkness of human prejudice. The results it accomplished in the social sphere through the dissipation of superstition, although overshadowed by the results in the sphere of the material world, have been of immeasurable importance.

The social sphere today is still a field that needs the light, a field in which the engineer with his training and point of view has open to him doors of rare opportunity. While not as sinister as the witchcraft problems, there are problems of prejudice in our social field that are, like witchcraft, based upon distrust and ignorance—problems that act as a brake on industry and separate man from man.

While I have dwelt upon the essentially economic character of the engineer's field and the social service rendered by him in the cultivation of that field, such social service is an indirect one, effected by his function rather than by a disinterested will to serve. For performing his function he receives compensation, and therefore it often is urged that he is not entitled to personal credit for social service, since he is paid for it. In the case of certain engineers, there is much weight in this criticism. It also is urged that much of an engineer's work comes under the head of business for which the professional status cannot be claimed, and that the only really professional engineer is the consulting engineer; who, it must be admitted, is usually an ornament to the profession and perhaps more conscious of a professional responsibility than many of his fellow engineers.

Similar questions have beset the older professions; and they have been worked out in a tolerably satisfactory way. No lawyer considers it a reflection, especially an ambitious young lawyer in a country district, to be referred to as conducting a law business; nor does a lawyer consider that he is not a member of the legal profession if he accepts an annual salary from a corporation for continuous service. Equally unaffected as to his professional status is the physician who works for a salary as distinguished from fees for general practice.

The essence of the professional status lies in the moral obligation involved in the act of professing. This act is always personal; and it is in the engineer's personal relations to his fellows and to society and the obligations therein involved, wholly over and beyond obligations for which he is compensated, that his professional status resides.

These moral obligations are the reasons why such particular weight is put upon character and integrity by the boards of examiners of the great national engineering societies before admitting to membership, and why violations of professional ethics rather than failures in professional competence have been practically the only grounds on which expulsions from these societies have been based.

Turning to the older professions for our models, we find that questions of personal obligation to fellows and to society constitute the very foundation of the professional conception. In these older professions the engineering profession has noble examples of the practice of obligations that are self-assumed and disinterested. The medical profession has its Hippocratic oath peculiarly pledging its novitiates to the service of mankind, irrespective of compensation. The legal profession, in its defense of penniless defendants and the vast amount of uncompensated service it renders to the courts and to the public as an arm of the law, illustrates its conception of professional service outside the field of compensation. As to the clergy, its objective is exclusively social, and its devotion is unmeasured by compensation.

Engineers themselves have been the first to recognize obligations that inhere in a growing consciousness of the professional status. Their great societies have been created not merely for self-education and intellectual development, but to give expression, in their relations with each other, with other professions, and with the public, to a desire for a standard of personal relations and for the recognition of obligations, beyond those which are pecuniary. Just as the peculiar equipment of the clergyman, the lawyer, and the physician gives him a peculiar power and authority when disinterestedly devoted to social betterment, so does the equipment of the engineer.

The engineer today finds himself in a pivotal position in industry, intermediate between capital and labor, with the problems of both of which he deals intimately and is in a position to understand, interpret, and judge. In consequence, there is offered to him entirely in addition to the service he performs through his engineering function, an opportunity for social service through his professional and personal status which, if he rightly conceives and seizes it, gives him a strategic advantage to render social service, which at this moment, the representatives of the older professions do not possess.

Is it too much to hope that with an enlightened method of approach and the habit of factual investigation which are the intellectual birthrights of the engineer, his increasing participation in management may bring to the solution of some of the social problems of industry a prejudice-dissolving light? Such a light is capable of showing the path to a new happiness in work, in which there is a recompense greater than all wages—joy in the act of creation. If there could come about a spirit of reciprocal confidence on the part of all elements, we could not fail to see increased production and increased leisure go hand in hand, securing those satisfactions deep in the consciousness of all Americans, which the immortal Declaration of Independence describes as the inalienable rights of life, liberty, and the pursuit of happiness.

To seize these opportunities for social service necessarily involves a demand upon the souls of engineers as well as upon their minds, which will be a test of their love of their fellow man. It is a case of *noblesse oblige.* Every engineer certaintly will have some occasion for meeting this test. When and as often as the test shall come, may none ever ask, in the words of Cain, "Am I my brother's keeper?" unless he already has resolved in his heart the intention to answer "I am."

Our Sons Specialize

But most scholars and industrial leaders consider a foundation in science and the humanities more valuable to the engineer than specialized technical training

By GILBERT E. DOAN

THE engineer's influence in modern society may be pictured by considering him as an energetic surgeon operating in a large and effective way upon the social organism. He is skilled in the use of instruments, but generally quite ignorant and unconcerned about the nerves and endurance of his suffering patient. His one-sided interest in tools and techniques begins in the engineering college where his teachers are content if he learns technology. Later, when he comes to apply the knife of modern science to the vitals of society, does he inflict needless pain? Does he suffer too? But can it truly be said that the average engineering graduate is uneducated? The academic-minded scholars may say he is, but that proves nothing. These scholars have forced a liberal education upon our physicians and lawyers. After all, the captains of industry employ the engineers. They might tell what training leads to long-range success. What do they say about our modern engineering education?

These leaders are keenly aware of the many strong features of engineering, but they condemn the narrowness of the present system in no uncertain terms. As men of vision as well as men of practical affairs they preach the same doctrine as the scholars: "Get the humanities and the foundations of science, but don't get technology. Industry will teach the man its technologic methods quickly enough. But industry cannot undertake to give him a liberal education or a sound scientific background if he comes without these."

What is this narrow training that the engineering schools give their students? A survey of representative engineering schools, conducted several years ago by the Society for the Promotion of Engineering Education, shows that the student in these schools received 30 per cent of his credits in basic science, 60 per cent in technology, and 10 to 15 per cent in subjects that can be called broadening or cultural—a little English, a taste of a foreign language, a bit of economics. A report published by the SPEE this year shows that the situation remains essentially unchanged. Evidently the student gets a good foundation in science and technology, but very little else. This evidence does not contradict the industralist's charge.*

But the 10 to 15 per cent of liberalism may be misleading. Perhaps the *spirit* of the engineering school is broad and liberal as it was in Germany before Hitler. It could be, but 20 years of experience in and out of such institutions both here and abroad seems to indicate that the American curriculum is not misleading. It truly represents the student's preparation for life. In spirit as in subject matter the typical engineering education offered in this country, possibly with a few exceptions, is essentially the same narrowly specialized schooling, involving for many fine boys the same spirit-stifling ordeal, the same growth-stunting régime today that it did when these industrialists were students. In fact, with the rapid advance of technology into new fields less room is left in the curriculum for the humanities than there was 35 years ago. The social upheaval of the thirties resulted in a measure of soul-searching on the part of engineering faculties, but so

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Essential substance of an article "Our Sons Specialize" published in the summer 1937 issue of *The American Scholar*, official publication of the United Chapters of Phi Beta Kappa, pages 294–303.

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*In September 1936, Massachusetts Institute of Technology took an important step toward liberalization by raising the percentage of humanistic subjects to approximately 17 per cent, running a band of 3 hours in humanistic fields through the entire 4 years. These courses have been integrated to avoid haphazard selection. Most important, perhaps, is the liberal point of view encouraged in the faculty by this step.

far it has led to little effective action.

Fresh out of high school the boy comes to college eager as boys are for a deeper understanding of the big things of life. He trusts his college to know what industry wants him to learn and to steer him wisely—a sacred trust if ever there was one. Enrolled as a freshman engineer he faces a stiff schedule of chemistry, physics, mathematics, and drawing. From 3 to 5 afternoons a week in the laboratory accompany them. He sees that he must shut out everything but science from his serious attention or fail his courses. In his sophomore year the intensity of specialization increases. The humanism encouraged in him at high school is effectively submerged. His budding intellect passes through a desiccating desert of abstract science—science which furthermore, so far as he can see at the time, has little significance for his chosen special field of engineering. For his vacations he gets practical experience by working in an industrial plant, and in his junior or senior year a little economics. That is all. His course contains 60 per cent of technology, including much semivocational training. Rapidly his broader interests atrophy under this pressure. Human problems become extraneous to his chief concerns, pale into unreality and vanish from his ken. If you want to see the result try reading a college magazine published by engineering students or talking to them about social security. The student is so busy learning new techniques that he has no leisure left for contemplating the significance of anything in college or out of it. He has no contact with history, biology, or philosophy.

As a result of this diet the most stimulating intellectual adventure that many a boy can remember at college is the fraternity "bull-session" prolonged into the wee hours of the morning. Here such vital topics as success, religion, morals, and marriage are discussed. If one boy in such a group were soundly informed on these subjects the discussion might be enlightening, but the engineering student must rely on casual heresay for the answers to humanistic problems, and the interests which such sessions stir in him are next day stifled.

Is this sacrifice of breadth in the boys' education justified? Fifteen years after these students have left their alma mater we expect to find them practicing engineering. Actually, less than 50 per cent of them are. Even the more successful of the engineering group are in positions where the managerial and administrative problems completely overshadow the technical. The farther these engineers advance, the less is the relative value of their technical training and the greater would be the benefit of a liberal education. Is the sacrifice justified for the boys of either group?

We have always believed that the "mental discipline" acquired in engineering studies will make men keener analysts in all the other problems they will meet. Many engineering educators still preach that doctrine. They don't realize that psychologists long since have shown that "mental discipline" is at best only partially transferable from one field of knowledge to another. Does your training in calculus, for example, enable you to grasp the roots of a labor situation one whit more surely than you could without it? No. We are compelled to accept what the scholars have long maintained: The engineer's schooling is of minor value in the advanced stages of his career and of even less value in his private life. Engineers we certainly must have, but must there be a lack of cultural balance in their preparation? If they are uneducated, has the college kept faith with the boys?

Even in the truly professional group a chemical engineer will find himself employed in the production of electric power, while a civil engineer manages a group of metallurgical furnaces. The conclusion will not down: The investment of undergraduate time in specialization is unwise.

Thus it is not the study of science that prevents our engineering students from getting a balanced preparation for life. It is the crowding out of an education by semivocational training. This overemphasis goes on in spite of the fact that industries can and do give vocational training to the graduates they select and do it better than the colleges.

Why, then, is the student given courses of this kind at college? In the first place the student gets them because his parents want him equipped to earn a better living, and they believe specialization is the best preparation. Having, in the majority of cases, no college experience of their own, they seek out the shortcuts offered by schools giving the earliest and most intensive specialization. In the second place the director of a student's curriculum is usually an engineering graduate and his own training was largely of this specialized kind. Specialties seem to the director essential to an engineering curriculum. They give it distinction, differentiate it from the indefinite "arts" curriculum. If it were too much like other curricula it might indicate lack of faith in the value of the special field. Certainly it would attract fewer students. Finally, the student gets the specialized course because he wants it. He can see what it did for the professor. It promises to prepare him for a definite career, which is more than "philosophy" promises. He hears there are good jobs open in that field. He likes the label, too. It has a ring of modernity that history and biology lack. Look at the expensive laboratory equipment used in the couse! That is what his high tuition buys. He should get all of it he can while the opportunity lasts. The enrollment for the course will be large, the students pleased with their opportunity and eager. What attitude could more surely warm the heart of a professor?

But don't the boy and his parents know that industrial leaders as well as scholars disapprove of specialized courses for undergraduates, that they consider a foundation in science and the humanities far more valuable than technical training? The answer is "no." They think that at least industrial leaders would strongly approve. Don't they know that at graduation the boy will take the best job offered, whether it is in his specially chosen field or not, and that the chances are several to one that it will not be?

When the subject of engineering school curricula is studied broadly, as was done in 1926–29 by the Society for the Promotion of Engineering Education, the need for liberalization is unanimously acknowledged. The society recommends that the proportion of liberal subjects be increased from 13 to 17 per cent. What have the engineering educators done about this recommendation, inadequate as it is? The report was read, no doubt, by the president of each institution and passed on to the curriculum directors with recommendation that it be perused thoughtfully. Each director will agree half-heartedly that liberalization probably is desirable, but always in another department, not in his own. The director of civil engineering will feel strongly that the electrical-engineering curriculum should be liberalized by dropping specialized courses, but that with civil engineering it is different. Perhaps as a concession to appearance a course in "railroads and terminals" would be moved from the "required" list and made "optional" with one in economics. He dosen't think "arts" courses are worth much anyway. He never felt the lack of them. The report gets as much action as the 1923 Carnegie report on professionalism in college football, although for a different reason. Our question "Why does the student not get the kind of education the industrial leaders and the scholars say he should have?" has now been answered; parents seek speculative shortcuts. The engineering educators are steeped in their own tradition, and that tradition is not liberal. Perennially the scholars have said engineering education was wrong from the idealistic standpoint. The industrial leaders now find it wrong from a practical standpoint.

The teachers of engineering are a group of sincere and capable men. Many have made noteworthy contributions to the technical aspects of engineering. But the price they paid was a life of narrow devotion. Only the exceptional man escapes the restricted outlook thus entailed. Their chief fault, if it be one, is this intense devotion to their own field and their undeveloped vision, often amounting to partial blindness in other fields. Usually they are not concerned with the broader problems of industry. In many cases it is their sincere belief that industry prefers men with a maximum of technical training, whether they are soundly educated or not. Thus even the changes that the farsighted leaders of engineering education agree upon in this direction do not receive very wide adoption.

Do the alumni who invested in these technical specialties at college later criticize their alma mater or feel resentment at the faculties which trained them so narrowly? Generally not. The alumnus enjoyed the prospect of an engineering career and the sincere enthusiasm of his teachers for their subjects. He saw the practical usefulness of the studies he pursued—even if they never were useful to him. When he left engineering he did so of his own free will. He had bettered himself by so doing. Anyway, college had been fun. "If I had it to do again I would take the same course" says the engineering graduate who has become a nontechnical executive. But you must note that the liberal-arts graduate who holds a similar job says exactly the same thing. One cannot expect him very ardently to long for what he doesn't understand. Few men regret what they did in a period of life which on the whole they enjoyed; few will bewail a deficiency they have later partly overcome. Most of the highly successful graduates are too busy and too tolerant to try to influence the educational policies of their alma maters.

This unsound state of affairs in the education of 50,000 bright boys a year should not continue. The preparation of engineering students should attain the standard agreed upon by both scholars and leaders of industry. And I believe it will. An adequate grounding can be achieved in 4 years. Most of the engineering specialties will have to be eliminated. To those who want them, specialties will be available in a fifth year.

Equally important, the attitude of engineering educators toward liberal education must change, for they hold the boy's complete confidence. What they tell him in these matters he accepts and will continue to accept as final truth. There is some evidence recently that their attitude may change but new and attractive fields of special technology are constantly being developed and parents and their sons will for some time continue to seek them as speculative shortcuts to success. So long as they are willing to pay the price the temptation to meet their wishes, however unwise, is great. The scientific foundation of the student's education will be preserved and augmented. But the capable graduate of the new type will have been prepared to act wisely in a broader sphere of affairs. When a labor crisis arises out of the use of one of his labor-saving machines, for example, his background of history, and perhaps psychology, will enable him to see the industrial situation in a clearer perspective. When a social security program is proposed, perhaps by thoughtless politicians, he will be able to understand at least the basic biological significance as well as the fundamental economic implications bound up in it for the future of the human race. He will have a right conception of the ends of life. Such vital questions as women in industry, the liberty of the individual in society, and crime will present themselves to him not as simple problems, it is true, but as matters resolvable into their component parts in the broad light of the great fundamentals of biology, economics, and history. He will be competent to see his engineering activities in their proper background and perspective, that is, he will be an educated man and not merely a technician.

Certain superiorities inherent in engineering education will certainly be preserved in the new version. Engineering education is professional education; it is purposeful and definite. In its liberalized form it will continue to supply dynamic and purposeful motivation to the student. Through this focus of his mind he will integrate the liberalizing and humanistic studies which must accompany professional training.

The faults of the present engineering education are not inherent in it. They can be eliminated without sacrifice and with great gain. Let one first-class college cut through the meshes of its illiberal traditions and the inertia of its vested interests. Let it frankly and wholeheartedly abandon the training of technicians in behalf of the education of engineers. Such a college need not fear for its future. To it will inevitably be attracted both a faculty to provide sympathetic administration of its program and a student body capable of profiting thereby. They will come from the better backgrounds where engineering education is now increasingly condemned. But the first step must be to set up a sound and attractive program.

Physics and the Engineering Curriculum

"Instruction in physics has been not only the mother of engineering, but for the future must be the heart of its instruction—its guide, philosopher, and friend"

By O. W. ESHBACH
FELLOW AIEE

ENGINEERING was originally the despised child of science. At the time of its birth, which occurred in a period of invention, it was not very welcome. In the second stage of its development, that of curriculum building which followed through a concurrent period of commercialization of inventions, many mistakes were made; and now since the beginning of the twentieth century, when it has been accepted the tremendous development of new ideas brought about by research in both colleges and industry have so swamped the all-inclusive efforts of curriculum builders that there is a threat of filial ingratitude. No matter how great the pressures are to limit time devoted to this instruction, it seems to be a false step to subordinate the importance of instruction in physics and likewise its financial support.

In recent literature on engineering education 3 ideas predominate as possible ways out. The first is, instruction should be more fundamental; second, the curriculum should be longer; and third, graduate study must be developed. All are in progress. This contribution, if it may be so graced, is a plea for the effective use of time, and it is in this relationship that instruction in physics is discussed. The simile for this thesis is taken from the field of electric traction, the speed-time curve. The principle is physical, common, and simple—the speed at which one travels determines the distance one can go in a given time and also the time to go a given distance.

Effective instruction in physics determines the quality and tempo of engineering teaching. Two of the important portions of a speed-time curve are the periods of acceleration and the portion when, after the maximum accelerating force has been applied, the motor operates in accord with its own characteristic. The peak velocity it will reach in a given time, operating on this characteristic, is affected by its rate of acceleration. Likewise, the stimulation given during the first 2 years of an engineering curriculum will be the determining factor in the speed of comprehension and effectiveness of learning of students during the latter part of their courses when, to a large extent, their own characteristics should determine the dimensions of their education.

This truth is axiomatic, but what most educators would like to know is how to do it. Some have attempted, with success, to crowd the maximum of mathematics into the freshman year, thus forming the background for a more effective study of physics in the second year. Those who have tried to introduce physics during the first year have found the necessity of continuing the instruction through the sophomore year. In either case it becomes perfectly obvious that a knowledge of mathematics and how to get it soon enough are 2 of the principal problems involved. The solution would seem to lie in an effort at integrating the early instruction in both physics and mathematics, limiting the instruction in early years to those new concepts in each field which are basic to the understanding, and early introduction of instruction in the several professional branches of engineering. To stop with the mere organization of instruction along these lines is insufficient. It is just as important that a procedure be made for stimulating teaching through a stimulating environment of adequate physical facilities. And to stop *there* is insufficient, because it would merely relegate physics to a subordinate influence in the professional thinking of students in later years. It would seem necessary to continue more advanced instruction through the junior and senior years.

This probably would mean the elimination of some of the specialized courses or options in the professional branches. The loss would not be serious, however, if time were saved by allocating everything that properly belongs in physics to that department. If such a procedure were attempted, it could only be accomplished through a co-operative effort on the part of the teachers of physics, mathematics, and engineering, which I believe would have to result in the scrapping of much of our standard text material, the development of a new technique of teaching, and a more advanced approach to the applications of science to engineering practice. An attempt in this direction would bring about an early development of intellectual capacity, a much greater speed of learning, the acquisition of more knowledge in the present 4-year period, and ultimately a more competent and better-educated professional body.

There are many weaknesses in our present situation. First, there is a failure to capitalize the interest which has led the most promising freshmen to select engineering as a career. This could be accomplished by an early introduction to physical concepts through the familiar types of

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Essential substance of a paper presented at a meeting of the Society for the Promotion of Engineering Education, Rutgers University, New Brunswick, N. J., May 15, 1937.

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engineering apparatus, giving both exactness of concept and quantitative approach. Because of large numbers of freshmen and inadequate facilities both in laboratories and teaching staffs there is not the personal contact with individual students which could be used for guidance and stimulation in a period now one of the most discouraging in a college student's career. In short, the physics department may be the first vocational guidance agency of the college.

Second, as instruction in engineering is now organized, it too often lacks co-ordination with physics, which often results in duplication of effort. While repetition is a good thing, it does not seem reasonable to a student that a curriculum frequently should require instruction in exactly the same subjects at exactly the same time, in 2 different departments. Co-ordination can be accomplished only by sympathetic understanding and willingness on the part of the faculties of both groups, not only to get together occasionally, but through faculty meetings of each group to meet regularly.

The problem of the physics department of engineering schools may be regarded as embracing 3 general objectives:

1. To instruct undergraduates in those principles of physical science which are essential to an understanding of engineering practice, and develop an appreciation of the relationships in these fields which will encourage the further development of their application.

2. To develop physicists, in addition to engineers, who will be able to carry on the future work in education and research which this important branch of science demands.

3. To develop in all students, technical or nontechnical, an appreciation of the scope, place, and importance of physical science in the modern world.

Considering the question from the limited view of a service function of the physics department should not be construed as a lack of appreciation or resentment toward glorifying the study of exact science as a plane of higher intellectual learning, but rather facing the fact that much of engineering is synthetic in character and must meet compromising and temporizing reactions of economic and human forces. Putting it in another way the engineer takes a utilitarian or practical attitude toward the study and application of physical principles. This fact does not alter the selection or determination of what should be taught, but is a vital factor in the stimulation derived from the way it is taught.

For example, if one were to examine good textbooks in each of the several engineering courses and list the physical principles involved in the understanding of them, by summarizing the results one would still say, teach mechanics, heat, light, sound, and electricity to freshmen and sophomores. These are basic physical phenomena from which applications have arisen through innumerable combinations of principles. Further investigation together with consultation with the faculty of the engineering college should hold promise of advantageous adjustments in time and emphasis given to the several basic courses, but the greatest values are to be obtained from understanding the body of engineering knowledge with a thoroughness that makes possible the selection of projects and problems to vitalize instruction in fundamental principles. Bluntly put, teachers of physics to engineers need to study engineering.

Another phase of the topic may be emphasized by rather sketchy illustrations. Progress in engineering is not stationary; in fact, it is one of the most swiftly advancing professions. With it the body of scientific and engineering knowledge has grown to proportions where serious consideration must be given to the time element in undergraduate education. Whether the situation will result in an extension of time or a modification of curricula, with greater emphasis on subjects in the field of mathematics and pure science, remains to be seen. In the meantime, teachers who are preparing engineers for careers 10 or 15 years hence cannot overlook the changes going on in practice and must attempt to anticipate the relative importance of new developments and viewpoints in the field of science. This refers more to instruction beyond the scope of what in the past has been regarded as the minimum fundamentals.

For example, in electrical engineering the last student generation has been giving increasing attention to the development of electronics with accompanying interest in the understanding of the physical nature of matter. Atomic physics, radiation, and high-frequency current phenomena are, as a consequence, edging into every curricula; in mechanical engineering the orthodox instruction in thermodynamic principles and applications is under pressure, and involves better understanding of the phenomena of internal energy, heat, and heat transfer and insulation; the industry of heating and ventilating and air conditioning is in a state of change; design is affected by the development of the art of welding; in civil engineering building materials are changing—the theoretical approach to stress analysis and fluid mechanics are viewed with a broader technical approach, in which the subjects of dimensional analysis and model structures are of increasing importance; in aeronautical engineering there is the most complicated application of mechanics to structures and fluids. All this seems to point to the necessity of greater exactness in physical concepts and the importance of perspective in dealing with related fields of practice.

It would seem, therefore, that the objectives of service functions of the physics department to the engineers should be: first, to teach thoroughly the minimum fundamentals necessary or prerequisite to beginning engineering subjects; and second, to organize the advanced courses so as to anticipate future requirements. The balance or emphasis given the subject matter must come from a knowledge of engineering practice and trends, in which co-operation with the engineering faculty is essential.

In closing, there are 2 aspects of the human side of the problem which are a part of the service. The first has to do with levels of ability and interest and the second with flexibility of occupational opportunity. Many students would profit by an engineering education; only a portion of them, however, will make successful engineers in a professional sense, and some never should study engineering because they have less than the minimum of ability required to profit by it. Can physics teachers in their instruction help the engineering division to solve these problems?

Regarding flexibility of opportunity, many engineers seem to be restricted in possibility of accomplishment by too early specialization, a good deal of which comes from a failure to appreciate the scope of application and co-ordination of technical knowledge in practice. Is it possible to bring under the influence of an independent department those subjects of engineering which are elementary, the co-ordination of which will broaden a student's viewpoint and stimulate his interest and curiosity? If there is any justification for such an attempt it would seem to be in the fact that industry is both a crucible and a catalyst for science, where personal opportunity easily can be hampered by premature decisions and prejudices.

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Use of the Slide Rule for Adding

By combining its ability to perform addition with its other functions, the usefulness of the slide rule may be greatly increased

By E. B. FERRELL

AS IT commonly is used, the slide rule serves as a set of tables and as a multiplying device. As the latter it also is used in performing the inverse operation division. By combining the 2 functions one may perform such operations as division by a sine, or multiplication by the square of a tangent. For many users the technique of slide rule operation goes no farther than such simple combinations.

By the inclusion of one more concept, however, the technique can be extended to include many addition problems, and a whole new field of usefulness may be opened up. The idea may be illustrated by a simple example. Suppose 18 and 45 are to be added; this may be written

$$18 + 45 = 18\,(1 + 45/18)$$

This reduces a general addition problem to one involving division, multiplication, and a very special addition. The division and multiplication can be performed on the simple slide rule. The special addition can be performed mentally. The only thing remaining is to arrange the work conveniently.

It is helpful to look upon the problem as a continued proportion. A series, 1, n, $n + 1$, is set up such that its third term is the sum of the first two. Next any other series is set up whose terms are proportional to those of the first series. Then the second series also satisfies the condition that its third term is the sum of the first two. The setting up of such a continued proportion is one of the easiest things to be done on the slide rule. In the numbers of the example,

$$\frac{1}{18} = \frac{n}{45} = \frac{n+1}{63}$$

This ability of the slide rule to serve as an adding device may be combined with its ability to serve as a set of tables. Squares and reciprocals may be added. To the communication engineer this immediately suggests the combining of impedances, either in series or in parallel.

Suppose the value of the impedance resulting from connecting 5 ohms in parallel with $j4$ ohms is to be computed. Since this is a parallel combination, reciprocals are involved. Since it is a vector combination, squares also are involved. In particular, a series of 3 numbers, 5, 4, and Z, are to be set up such that the squares of their reciprocals will form one of those series whose third term is the sum of the first two. Now on the ordinary polyphase slide rule, the numbers on the B-scale are the squares

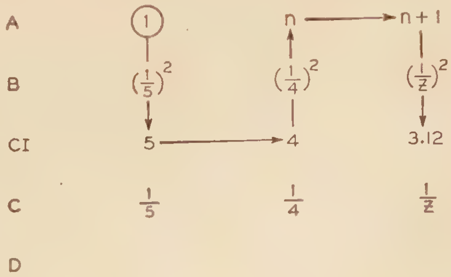

Figure 1. Setting of the slide rule for computing the absolute value of the combination: 5 ohms in parallel with j4 ohms

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Written especially for ELECTRICAL ENGINEERING.

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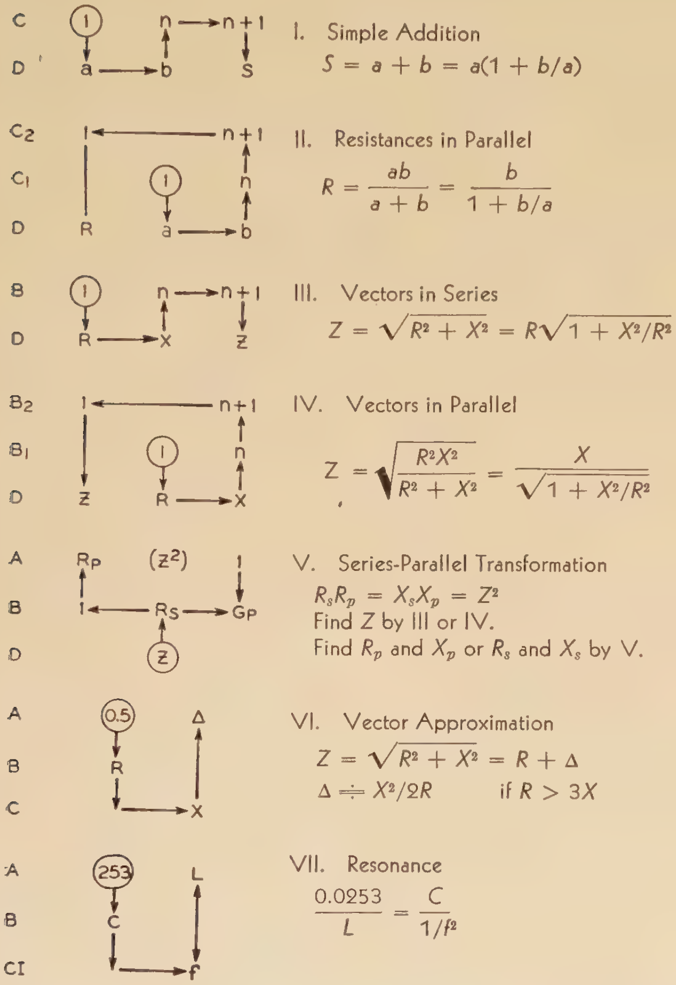
of the reciprocals of numbers on the *CI*-scale. And numbers on the *A*-scale are proportional to numbers on the *B*-scale. Therefore, the problem may be solved by reading the numbers 5, 4, and *Z* on the *CI*-scale so that the squares of their reciprocals, on the *B*-scale, lie opposite the series 1, *n*, *n* + 1, on the *A*-scale. The face of the slide rule as set up to perform the required operations is shown diagrammatically in figure 1. The letters at the left of the figure are the names of the scales involved. A vertical line indicates the alignment of 2 numbers on different scales, as may be done with the aid of the runner. The circle encloses the number first used and the arrows lead to the various numbers of the problem in the order in which they are used. No explicit use is made of the number $^1/_5$ on the *C*-scale, or the number $(^1/_5)^2$ on the *B*-scale.



I. Simple Addition

$S = a + b = a(1 + b/a)$

II. Resistances in Parallel

$R = \dfrac{ab}{a+b} = \dfrac{b}{1 + b/a}$

III. Vectors in Series

$Z = \sqrt{R^2 + X^2} = R\sqrt{1 + X^2/R^2}$

IV. Vectors in Parallel

$Z = \sqrt{\dfrac{R^2X^2}{R^2 + X^2}} = \dfrac{X}{\sqrt{1 + X^2/R^2}}$

V. Series-Parallel Transformation

$R_sR_p = X_sX_p = Z^2$

Find Z by III or IV.

Find R_p and X_p or R_s and X_s by V.

VI. Vector Approximation

$Z = \sqrt{R^2 + X^2} = R + \Delta$

$\Delta \doteqdot X^2/2R \qquad \text{if } R > 3X$

VII. Resonance

$\dfrac{0.0253}{L} = \dfrac{C}{1/f^2}$

Figure 2. Diagrams showing some of the operations that may be performed with a slide rule

In undertaking to apply this extended technique to various problems, there are several possible ways of performing the actual operations—just as there are several ways of performing a simple multiplication. The particular arrangement chosen for the last example, while good for purposes of illustrating the principle, has 2 disadvantages from the operating viewpoint. The result appeared on the slide, where it could not be used directly for subsequent operations. The arrangement involves the use of the *CI*-scale which does not appear on the simple Mannheim rule.

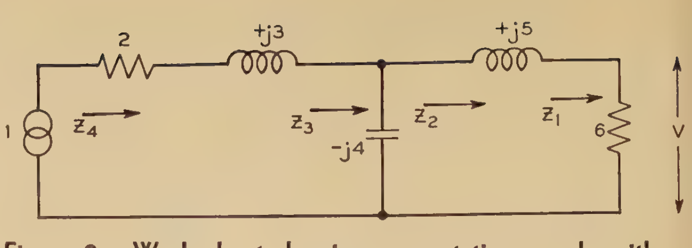


Figure 3. Work sheet showing computations made with a slide rule

The voltage *V* is computed from the constants given in the circuit diagram. Arrows are used to indicate equivalences, and show the order in which the operations are performed. The symbol ‖, an adaptation from elementary geometry, indicates "in parallel with"

$Z_1 = 6.00 \qquad = 6.00 \;\angle 0^\circ$

$\qquad\;\; \underline{+\,j\,5.00}$

$Z_2 = 6.00 + j\,5.00 \rightarrow 7.81 \;\angle{+39.8^\circ} \rightarrow 10.17 \,\|\, + j\,12.20$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\; \underline{-\,j\;4.00}$

$Z_3 = 2.59 - j\,4.43 \leftarrow 5.14 \;\angle{-59.6^\circ} \leftarrow 10.17 \,\|\, - j\;5.95$

$\qquad\; \underline{2.00 + j\,3.00}$

$Z_4 = 4.59 - j\,1.43 \rightarrow 4.81 \;\angle{-17.3^\circ}$

$$V = \frac{1 \times 5.14 \times 6.00}{4.81 \times 7.81} \;\angle 0^\circ - (-17.3^\circ) + (-59.6^\circ) - (+39.8^\circ) + 0^\circ$$

$$= 0.820 \;\angle{-82.1^\circ}$$

The set of diagrams in figure 2 shows convenient methods of performing a few of the operations that may be of interest to the communication engineer. In some of these operations the slide, instead of the runner, is shifted. Successive positions of the movable scale are indicated by subscripts. It may be noted that only a single shift of either the runner or the slide, but not of both, is required to complete most of the operations indicated.

Nothing has been said about the location of the decimal point. Rigorous rules for this are both complicated and unnecessary. In vector work more help will be obtained from a visualization of the vector triangle.

No mention has been made of the phase angle. Unfortunately the trigonometric scales of the Mannheim rule are not located conveniently for inclusion in the technique described. Fortunately the angle itself is often not of great importance. When needed it can be found by a separate simple operation. But it may be noted that the "*n*" in either of the vector operations is the reciprocal of the tangent of the angle. If at the start the index always is set over the *smaller* of the 2 vectors, then only the addition of an inverted tangent scale on the face of the slide is required to make a full-fledged vector slide rule out of the simple Mannheim rule. The first decade of this scale is sufficient for most purposes.

In preparing this discussion the objective has been not the presentation of a new formula or a new trick, to be forgotten as easily as learned, but the encouragement of a viewpoint that would lead to wider and more satisfactory use of the simple slide rule.

Protective Multiple Earthing in England

From the results of an investigation conducted in 4 typical villages in England, recommendations for improving the protective earthing (grounding) of rural electric circuits in that country have been made

INVESTIGATIONS to ascertain to what extent consumers of electricity in rural areas of England are protected from risk of shock with methods of earthing at present in use, and what changes in practice might be desirable, with special reference to "protective multiple earthing," were reported in a paper by H. G. Taylor entitled "The Use of Protective Multiple Earthing and Earth-Leakage Circuit Breakers in Rural Areas" which was read before The (British) Institution of Electrical Engineers, April 14, 1937. The term "protective multiple earthing" as used here means the connection to earth of the neutral conductor at some or all consumers' premises and the connection of metal frameworks to the neutral, using a separate insulated earth-continuity conductor that is run through the house and connected to all metal-work of appliances, to a separate earth, and to the neutral service conductor on the service side of the fuses at the meter board.

The investigations show that present safeguards are inadequate. Recommendations are made which it is believed will lead to material improvement, but further experience and experiment are said to be necessary before the matter can be put on an entirely satisfactory footing. Figures 1 to 4, reproduced from figures 1, 2, 3, and 10, respectively, of the paper, give some of the principal results.

It has been realized for some time that in rural areas fed by overhead lines where no water mains exist the protection afforded by "ordinary earthing" is not entirely satisfactory. With this in mind an investigation was undertaken by the British Electrical and Allied Industries Research Association with a view to finding means for improving the situation. Alternative methods of protection are provided by earth-leakage circuit breakers, or the use of the neutral to carry the fault current. This latter method, known throughout the paper as "protective multiple earthing" is subject to the disadvantage that the frameworks of apparatus connected to the neutral rise to the same voltage above earth as the neutral conductor. It was found from field tests, however, that the voltage rise of the neutral did not exceed a value dangerous to human beings under normal operation, and that even animals would be protected if the statutory voltage drop were not exceeded. No interference with the satisfactory working of the telephone system was observed during any of the tests.

Other possible sources of trouble due to the use of the protective multiple earthing system were considered in some detail. An investigation also was made to find the tripping voltage of earth-leakage circuit breakers that have been in use for a period of about 2 years.

Conclusions and Recommendations

The paper concludes with the following major deductions reached from the practical tests, conclusions re-

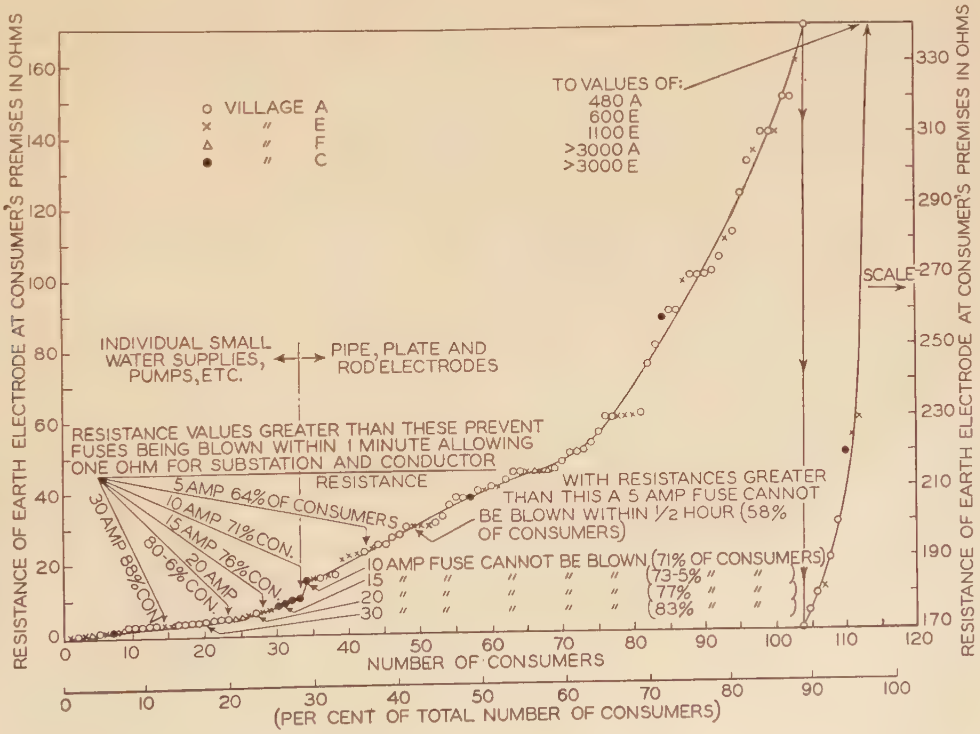


Figure 1. Resistance of earth electrodes at consumers' premises

In none of the villages does a general system of water mains exist, though in many cases it was found that consumers had a pump which drew water from a well in the garden, and these were generally used for earthing. The value was always 10 ohms or less, and the figure shows a clear discontinuity in the curve at 10 to 15 ohms, between the resistance of pumps, water systems, etc., and that of earth rods or plates

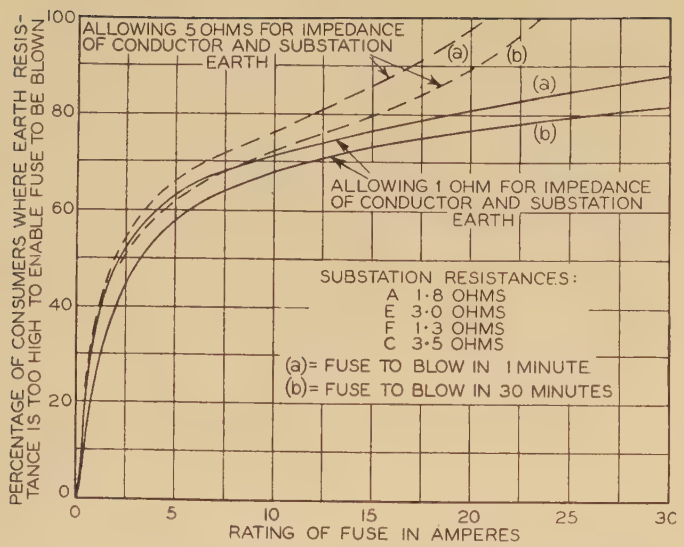


Figure 2. Percentage of consumers at each of the villages where fuses of various sizes cannot be blown

specting protective multiple earthing in general, and recommendations respecting existing and new installations and certain proposed conditions which should be complied with before protective multiple earthing is permitted:

Conclusions on the Practical Tests

1. If the results of measurements made at 4 villages in different parts of the country may be regarded as typical, in $^{2}/_{3}$ of the installations in rural areas fed by overhead networks, where no water mains exist, fuses could not clear an earth fault due to an insulation breakdown on electrical appliances.

2. Tests in an area where the earth resistivity is high have shown that earth-leakage circuit breakers, while not in all cases functioning at a voltage below the danger limit (*viz.*, 30 volts), have contributed materially toward eliminating the risks of electric shock. Moreover, many of the tests were conducted on early types of circuit breakers, and with the improved types now available and the development of technique there is good reason to expect better results in the future.

3. Tests on protective multiple earthing have shown that the voltage-rise of the neutral with respect to earth under quite abnormal conditions of loading does not exceed 30 volts and is therefore not dangerous to human beings, though it may be dangerous to animals.

4. When using protective multiple earthing, immediately prior to the blowing of fuses the voltage rise of the neutral at the end of distributors and near the substation may be 60 volts to earth for a short period.

5. If the statutory limits of voltage variation are adhered to, the voltage rise of the neutral will not be dangerous to either human beings or animals.

6. The voltages picked up on pilot lines to test earths adjacent to power earths were smaller than would be required to produce false ringing of telephone bells in the C.B.S. No. 1 type of exchange, and listening tests on the telephone lines did not reveal any disturbance.

7. Substantial improvement could be effected in existing installations using the present method of earthing by—

(*a*) Ensuring that an electrode not less than 6 feet long and not less than $^{3}/_{4}$ inch in diameter is always used, and that, if necessary, 2 are used at least 6 feet apart.

(*b*) Making use of a small water-pipe system, if one exists in the village, as the earth for the neutral, instead of attempting to provide an earth of low resistance at the substation.

(*c*) Making greater use of a protective earth wire for interconnecting the metal-work in a group of houses, and joining it to earth at a house where a low earth resistance exists.

8. The effect of multiple earthing of the neutral is to reduce the voltage drop in the neutral and earth in parallel to a greater extent than would be expected from the change in resistance; at the same time the voltage-drop in the phase wire is increased.

9. Multiple earthing of the neutral does not appreciably improve the voltage regulation.

Conclusions on Protective Multiple Earthing in General

1. If the connection between the protected metal-work and the (insulated) neutral is made only at the meter board, a fracture of the neutral wire inside the installation does not represent a hazardous condition—the appliance merely ceases to function. If a fault to frame exists, current returns through the neutral wire and the earth-continuity conductor in parallel, and entirely through the latter if a break in the neutral occurs. As this may constitute a fire hazard if it continues for any length of time, it is essential that no fuses or switches should exist in the neutral.

2. The voltage rise of protected metal-work in the event of a fracture of a neutral service conductor, without the phase wire, is determined by the connected load and the earth resistance at the consumer's premises. For example, on a 240-volt supply, if the resistance is 10 ohms and the load switched on is 1 kw the voltage rise is 36; if the resistance is 100 ohms the value is 152 volts. The voltage rise is in no case equal to the full supply voltage, which is the voltage which may occur on metal-work ineffectively earthed in the ordinary way, unless there is no earth at all on the consumer's installation.

3. In the event of a break in a neutral distributor without the phase wire all the metal-work on the system rises to a certain voltage with respect to earth, which is determined by the connected load on the remote side of the break from the substation, and the resistance to earth of the neutral on either side; if the break is near the substation the voltage on the frameworks of appliances connected to the sound section of the neutral is higher than that on those connected to the disconnected section; if the break is nearer the end of the distributor than the substation the reverse is the case. From the point of view of general danger the worst position for the break if the system possesses only a single distributor is at 30 to 40 per cent of the distance from the substation to the end of the distributor with a

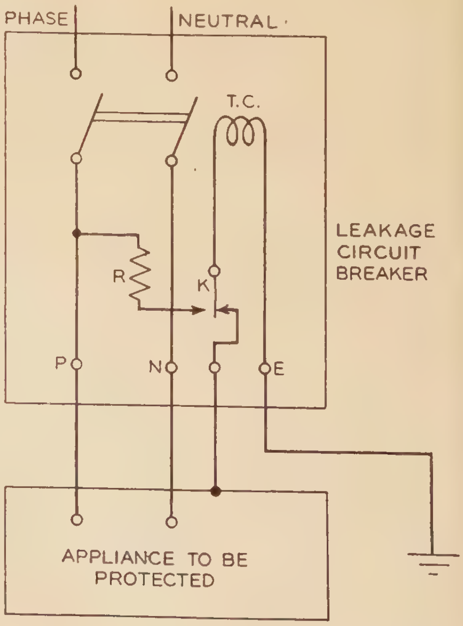


Figure 3. Diagram of connections of earth-leakage circuit breaker

uniformly loaded and symmetrically earth system. The lower the general resistance to earth of the neutral, the less the voltage rise.

4. Comparing the system of protection by earthing which is at present used, with protective multiple earthing, from the point of view of shock risk, it is estimated that the latter system is several times as safe as the former.

5. With protective multiple earthing, a line-to-neutral fault on the distributor of a 240-volt system would not result in a greater voltage than 60 volts on protected metal-work, provided precautions were taken in effecting the earth connections to ensure that the true neutral point is near the load center of the system.

6. A disadvantage of protective multiple earthing of the neutral is that current returning from an earth fault on the phase wire cannot be distinguished from normal neutral return current.

7. Existing installations may readily be converted to the protective multiple earthing system by connecting the earth-continuity conductor to the neutral at the meter board and linking across all neutral fuses.

Recommendations

1. That protective multiple earthing be permitted, subject to compliance with the conditions laid down below.

2. That farm installations where animals may come into contact with protective metal-work should be treated differently from house installation, in view of the greater sensitivity of animals to shock than human beings.

3. Since small water systems frequently occur at farms it is suggested that such installations only continue to be earthed in the usual way, provided that the total resistance in the earth circuit at any time of the year is low enough to pass $2^1/_2$ times the current normally carried by the largest fuse on the installation. If this is not possible then earth-leakage circuit breakers should be used on each distinct piece of apparatus and *all* frameworks and metal-work in the installations, liable to become alive, should be protected, where there is danger of animals making contact with the metal-work. The trip-coils should operate at not more than 15 volts.

4. If undertakings decide to continue to rely on ordinary earthing, the resistance in the total earth circuit should be such that the earth current which will flow at any time of the year, in the event of an earth fault, will be $2^1/_2$ times the current normally carried by the largest fuse in the installation. If this cannot be ensured then ordinary earthing should not be relied upon, and protective multiple earthing or earth-leakage switches should be used.

5. If earth-leakage circuit breakers are used, care should be taken to ensure that *all* metal-work throughout the installation which is liable to become alive is protected.

6. That a British Standard Specification be prepared for earth-leakage circuit breakers.

7. That greater attention be given, in the construction of all electrical appliances, to the provision of a higher standard of insulation.

Proposed Conditions Which Should Be Complied With Where Protective Multiple Earthing Is Used

1. The size of the neutral distributor should not be less than that of the phase wire, and both conductors should preferably not be less than 0.05 square inch.

2. The neutral should be connected to earth at all consumers' terminals—the earth electrode consisting of any water pipes that are available or a single 6-foot mild-steel rod of not less than $^3/_4$ inch diameter or a pipe of 1 inch diameter. The pipe or rod should be driven as nearly vertically as possible, and the connection to the electrode should be made above the ground surface so that it may be inspected.

3. The neutral distributors should be connected to earth at the base of poles at 4 points per route-mile, in addition to the earth at the substation. Including the substation the ratio of any 2 of these resistances should not exceed 4, and the greatest should not exceed 10 ohms,* and should preferably be considerably less.

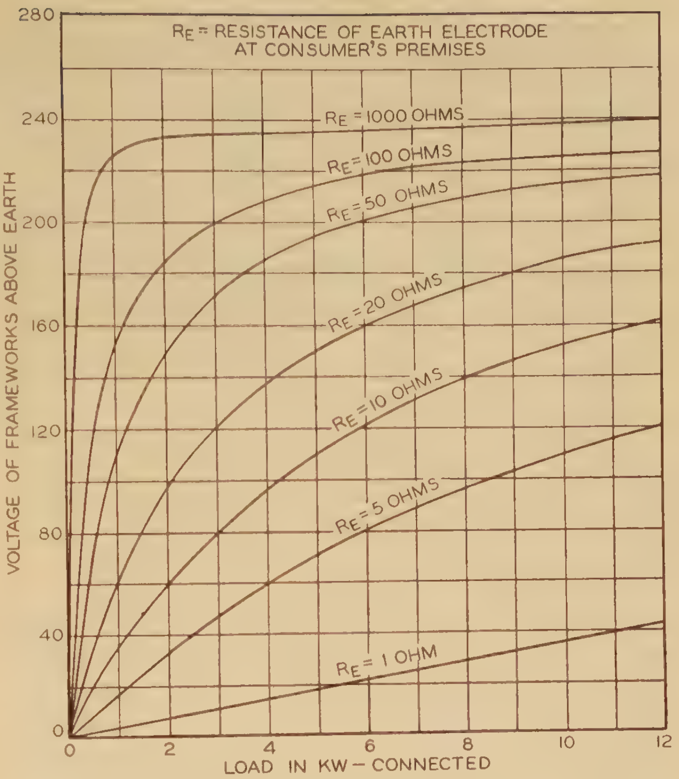


Figure 4. Voltage above earth of protected frameworks for various values of earth resistance and installed capacity when a break occurs in a neutral service conductor

4. Water mains should not be used for earthing at the substation.

5. An earth-continuity conductor should be used throughout each installation, and should be connected to the neutral conductor and earthing lead at the meter board.

6. No switch or fuse should be used in the neutral throughout the installation, but removable links may be provided for test purposes where required.

7. The resistance of the earth continuity conductor from any appliance to the meter board should not exceed 0.5 ohm, and this should be verified in each installation by means of a current of at least 10 amperes flowing for 5 minutes, before protective multiple earthing is used.

8. Two separate electrodes should be provided for earthing: (*a*) the high-voltage system neutral point and/or any metal-work related to the high-voltage system and electrically separate from the metal-work of the low-voltage system, e.g., the earth wire; and (*b*) the low-voltage system neutral point and the metal-work of the low-voltage system. These should be so situated that the low-voltage earth electrode is not within the resistance area of the high-voltage earth electrode. If this precaution were not taken, then a breakdown on the high-voltage system, causing current to flow through the high-voltage earth electrode, would result in the potential rise of the high-voltage earth electrode being communicated to the neutral of the low-voltage system and all apparatus frames connected to it.

9. The distribution system should be so protected that in the event of contact between a phase wire and neutral at any point up to the consumer's terminals the supply would be automatically cut off from the defective section.

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* In areas where the resistivity is exceptionally high it may be necessary from economic considerations to permit a higher value of resistance than 10 ohms.

A Review of Radio Interference Investigation

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Development of radiobroadcasting and reception has been paralleled by development and extensive use of devices that may cause interference with reception. The purpose of this paper is to review several factors of particular interest to the electric utilities, who supply service to both the radio and many of the interference sources. A relatively new form of interference effect—external cross modulation—is described. In conclusion, a parallel is drawn to the familiar co-ordination activities on wired communication lines and electric power systems.

RADIO has advanced from a little known hobby of 15 years ago to a publicly accepted source of entertainment, news, and education today. Modern receivers with high sensitivity, wide frequency coverage and high fidelity, represent an almost phenomenal development from the battery-operated sets of 10 years ago, and the crystal sets of a few years previous.

Self-contained, compact receivers, capable of being operated without special antenna and ground connections, have replaced the older sets which required a large cabinet, miscellaneous connections, and an outside antenna. A short piece of wire along the floor or wall for an antenna, and no connection to a ground post, are features of minimum installation trouble. A connection to the nearest electric outlet has replaced the batteries and eliminators.

Expectancy on the part of listeners for absolutely noise-free reception has increased the level of freedom from interference expected. In contrast to the thrill of hearing a distant station, even if only faintly and between crackling noises, is today's immediate annoyance at any snap, buzz, or break in good, clear reception. This attitude is, in itself, highly complimentary to those who have made it possible.

Increase of Interference Sources

In this same period, development and increase in use of electrical appliances has paralleled radio development. Along with lights there are now in the same homes with radio receivers, one or more of the new appliances—electric refrigerators, mixers, cleaners, blowers on heating and cooling systems, oil igniters, stokers on furnaces, and now even electric razors. These devices employ motors, thermostats, control contactors, etc., which may contribute to radio-frequency disturbances.

High-frequency equipment, such as X-ray and therapeutic apparatus, formerly confined to hospitals, is now located in doctors' and dentists' offices in every commercial center. Flashing commercial neon signs are common and electric precipitators and other industrial devices may contribute to radio-frequency disturbances over a wide area.

In the majority of cases, interference from these sources is confined to the same building or room, but in other cases the disturbance may be severe enough to carry over electric service lines which are common to several buildings and reach receivers in the neighborhood. In particularly severe cases, the high frequency has been known to spread through space and over distribution circuits and cause interference over an area of several miles radius.

These conditions summarized briefly are:

(*a*) Sensitive, compact a-c receivers with short inside antennas.

(*b*) A wide band of frequencies to be received and an increasing interest in short-wave foreign broadcasts.

(*c*) A more discriminating and widespread group of listeners.

(*d*) A large increase in possible sources of interference and in the density of these sources.

Utility Interest in Interference

Electric distribution equipment of the utilities was originally one of the principal causes of radio interference. Loose connections at cutouts, taps and terminals, and arcing at insulators and to grounds, were the principal causes encountered. Tests, inspections, laboratory research, design changes, and maintenance have, in general, removed this source as a widespread cause, but cases of loose and corroded connections and faulty equipment still occur often enough to require investigation of complaints. Investigation on the lines has now been largely reduced to locating individual cases of breakdown and repairing or replacing of defective parts.

Interference carried by distribution lines, service wires, and inside wiring, is of more importance now, partly because it is not so easily eliminated. Some of the interference from appliances is directly transmitted, but in other cases electric circuits serve to carry it. The principal rôle of the electric circuits is shifted from that of direct influence or cause to the field of carrier or coupling.

Investigation of radio interference complaints has generally been taken care of by the public utilities, in the United States. This rather liberal policy has been a gradual development and may be considered as promoting customer good will. The utility cannot say that its equipment is not causing trouble, without an investigation, because such cases still occur. The utility's inspector can

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A paper recommended for publication by the AIEE committee on communication. Manuscript submitted July 23, 1937; released for publication August 17, 1937.

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The authors wish to acknowledge the assistance given by W. J. Wuest and W. L. Thompson, Cincinnati Gas & Electric Company, in the interference inspection procedure outlined, and by the technical supervisors of Cincinnati radio stations, particularly R. J. Rockwell, of Crosley Radio Corporation, for co-operation which has led to a practical application of the co-ordination idea.

usually trace down the real cause at a moderate additional cost.

A less tangible result of public acceptance of radio is of inestimable value to the rest of the electrical industry. Radio has contributed to the public's knowledge and intimate familiarity with electrical apparatus. This must inevitably help to stimulate an interest in all electrical development.

Portable radio receivers have been used by a number of companies in line patrol work, to locate trouble in its initial stages. Investigation of radio interference complaints, which lead to the location of defective distribution and transmission line parts and loose connections before they develop far enough to result in line outages, may in itself go far to balance the cost of such investigation.

Where the utility's policy is to investigate all complaints received, an average of about 20 per cent justified complaints from power causes has been found during the past few years by The Cincinnati Gas & Electric Company. The number of power causes is only about 25 per cent of what it was in the first years of this investigation work. The frequency rate of complaints averages one complaint per year per 300–400 residential customers. The cost of these investigations to the utility, in general, approximate only about 1 or 2 per cent of the revenue derived from radio. Incidentally, Edison Electric Institute statistics show radio receivers as a consumer of total kilowatt-hours second only to electric refrigerators, among domestic appliances.

Causes of Interference

Radio receivers respond to impulses of minute quantity, in the range of frequency for which they are designed and adjusted. Whether these impulses come entirely from a desired broadcast station, or partly from other nearby sources, determines the degree of freedom from interference. The ratio of signal strength to noise level is important. Radio interference is a purely relative situation. Many of the causes of interference today would have been entirely unnoticed with the old-type receivers and antenna installations.

Excluding natural or atmospheric static and set troubles, there are 2 common classes of interference, and a third class that is less known. The most common causes are those associated with load current passing through poor or loose connections in circuits or equipment and generating radio-frequency energy.

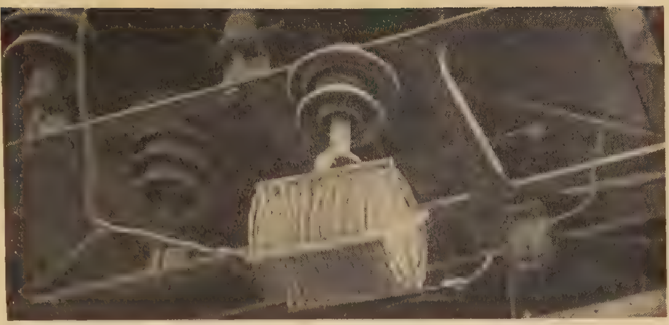


Figure 2. Radio-frequency choke applied to an industrial precipitator

Before this source of interference was located, interference had been found as far as 2 miles distant

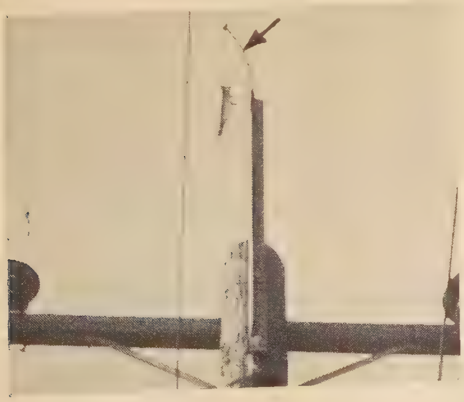


Figure 1. Flexible jumper on swivel static clamp

The loose connection of these clamps to ground the static wire is sufficient for lightning surges but not as a drain for radio-frequency energy picked up by the static acting as an antenna

Somewhat less common are the cases of static discharges to ground, from electrical conductors or charged bodies, but not associated directly with load current. External cross modulation is a relatively new class of interference, somewhat similar to static discharges but with other factors associated with broadcast energy.

Some of the more common causes associated with sparking or loose contact are: connections in the house wiring; at the appliance or outlet receptacle; in the entrance connections or outside in the service connections; secondary lines; or transformer installation equipment. Other causes include slip-ring and commutator sparking in motors; thermostatically controlled loads of all types, from the household aquarium heater of a few watts to the industrial electrical heaters of many kilowatts capacity; synchronous rectifiers of X-ray equipment and industrial precipitators; therapeutic devices; elevator controls; dial telephones; electric railway equipment, trolley and motors; and a host of others.

A few of the common causes of the static discharge type of interference are the alternate charging and discharging of household refrigerators by belt static; worn extension cords touching metallic frames; armored cable loosely touching against grounded piping and discharging whenever vibration causes contact. Primary distribution line causes include insulated conductor arcing to hardware; line wires arcing to guys or trees; street lighting fixture troubles; loose tie wires at insulators; and loose ground connections on overhead ground or static wires.

Fortunately, the majority of the more common causes of arcing type of troubles are fairly easy to locate and eliminate. Remedy may vary from tightening of connections to the application of chokes or condensers. Many electrical devices now have built-in capacitors which are very effective. Static discharge causes are eliminated by increasing clearances, by bonding, or solid grounding.

There is no "cure-all" type of corrective or mitigative measure, nor does there appear to be any general rule for the elimination of interference. Some of the commercial so-called interference eliminators have been nothing more than small condensers. Other "eliminators" ground the receiver antenna terminal and use the house wiring for an antenna.

The conclusion may be stated that in most instances, elimination of severe interference requires location and correction at the source. Since, however, the absolute elimination of all sources does not appear feasible or practical, it is essential that receiver antennas should be properly installed, and free from, or shielded from, surrounding wires. Short inside antennas, which pick up the broadcast energy by reradiation from the house wiring, will naturally be much more susceptible to even slight influences.

External Cross Modulation

This is a relatively new term in the field of interference investigation. The explanation is at present more theoretical than proven, although the evidence of it is definite enough. To the radio listener the effect is that one station is heard in the background when the receiver is tuned to another. In extreme cases, the background station may actually predominate. This form of interference must be differentiated from cross modulation within the receiving set itself.

External cross modulation is a field strength modulation produced by a strong signal in conjunction with another signal, where both act upon a system of wires or metallic structures in which there is a variable impedance element affected by the radio-frequency-current pulsations. This metallic system then reradiates the desired signal which, due to the variable impedance, contains the modulation of the other signal.

If the receiver antenna is in the field of the reradiated signal, there will be both direct radiated and reradiated energy entering the receiver. The severity of cross talk or cross modulation depends on the ratio of these 2 energies.

Rectification at a poor connection will also result in the generation of harmonics of the actuating frequencies, as well as heterodyne frequencies obtained by the addition and subtraction of fundamental frequencies and combination of fundamental and harmonic frequencies.

Elimination of this type interference requires properly installed antennas, solid grounding of neutral service wires, and clearing of loose connections in surrounding piping, plumbing, and metallic surfaces. Contact between any metal bodies of sufficient size, if the contact is oxidized, will cause rectification and hence cross talk or cross modulation.

Investigation of Complaints

In the interest of service and good will, it is necessary that the electric utility investigate radio-interference complaints made by its customers. Considerable variation in the company policy is possible—from one of investigating every complaint, tracing the trouble to its source and correcting the condition regardless of its nature, to investigating only those assigned definitely to the utility by a competent radio service man. Efforts to curtail the field work involved have included letters listing several questions to be answered by the complainant before the investigation is made, as well as, in a few cases, a charge fo investigations made that do not disclose a utility source o interference.

In some cases, an extremely liberal attitude has resulted in the utility becoming almost the first point of call for all sorts of radio trouble. This is, perhaps, as undesirable as the opposite extreme of having customers feel that the utility is barely willing to clear its own trouble to correct interference.

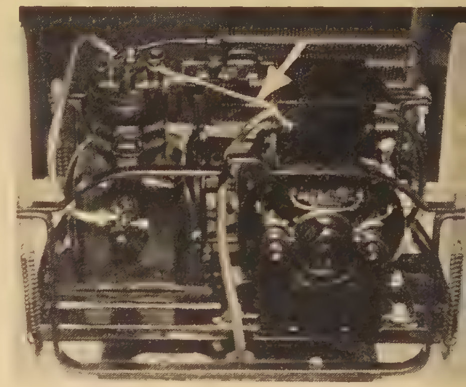


Figure 3. Eliminating belt static in a domestic refrigerator

A small copper-wire jumper is used to bond the motor and compressor

A moderate policy seems to be that the utility should have an inspector make personal contact as promptly as possible, identify the interference, classify its intensity, and locate the cause of trouble. If interference is found to be caused by utility equipment, the condition should be corrected, or mitigative measures applied. If the interference is found to be caused by appliances or devices owned and operated by utility consumers, an attempt should be made to either apply or suggest corrective or mitigative measures.

Cases of radio-receiver trouble should be referred to the customer's radio repairman. Many, and perhaps a large percentage of complaints will lead to trips by the inspector only to find that the interference was only on a short time and has disappeared, or that the complainant has found the trouble, or also called a service man to check the receiver. Here, as in cases of actual interference, tact and an attitude of personal interest on the part of the inspector, are a definite asset to the utility in maintaining consumer good will.

The most useful tool of the inspector in following this policy of investigation, is a standard receiver. Use of this set isolates the cases of receiver trouble. The procedure is then to follow back and by elimination of possibilities finally isolate the source of trouble. During this part of the investigation, the inspector should also check the antenna.

In most cases, it is permissible to open the entrance switch in residences, and a test made here with the test receiver connected on the line side of the switch, will definitely show whether the trouble is within the premises. If it is, the branch circuit can be located in a similar manner.

These first steps are made on the supposition that the trouble is on the premises of the complainant. The average experience under the moderate policy outlined above, is that two-thirds of the total complaints received will be cleared or isolated at this point, including the cases of receiver trouble, unfounded complaints, and disappeared interference.

The next step in the remaining one-third of investigations, is outside the complainant's premises. Here the investigation becomes more technical in nature and follows along the lines of experience in the past. The principal point of difference under conditions of the last few years, compared to the earlier years of radio, is the very large proportion of complaints that can be eliminated without the use of special investigation equipment for use in the field.

It is important that a record be kept of each complaint received and the investigation made. It is helpful to have a method of classifying the complaints on this record, so that summaries may be made and the work reviewed. Instruments are available for technically classifying interference levels, but a practical method that is easily applied on the first investigation is to compare the signal to noise ratio, at various points on the dial. The essential information is field strength or intensity of the interference and its duration.

A notation R_2 *ABC* F_4 on the complaint report, representing an interference that is equal in interference to station *ABC* at the location of the test with the antenna system on the premises, and that the interference is continuous, gives a helpful record.

With this method of notation, R_0 is used to represent inaudible interference and the grading is up to R_3 where the interference blankets the signal. For time frequency notation, F_0 represents very infrequent, F_1 minutes per day, up to F_4 representing continuous.

This method is being used to replace exact data obtained from field-strength instruments and the notations are more easily understood in this form than in terms of microvolts per meter. This does not preclude, however, the necessity of accurate instruments for more technical field strength and interference investigations.

Radio Co-ordination

Radio-interference elimination is essentially to co-ordinate this use of electricity with its other uses for light, heat, power, and transportation, in order that the growth of each may not be restricted by the requirements of the other.

The complete elimination of all radio interference would involve an enormous sum of money. A reasonable level, which is economically feasible, is the best that can be hoped for. Ratio of broadcast field strength to noise level field strength, both natural static and man-made interference, is an important part of the problem.

Legislation has, in a few instances, been provided by states and cities in the United States. Serious enforcement of such laws and ordinances would be cumbersome and expensive. Individual offenders who knowingly and persistently operate interference-producing devices and refuse to co-operate in application of necessary remedial measures, are rare.

A highly effective approach to the inductive interference problem caused by proximity of telephone communication circuits and power circuits, has been through recognition of 3 subdivisions of the factors involved: (1) inductive influence of the power circuit, (2) inductive susceptiveness of the telephone circuit, and (3) inductive coupling between the 2 types of circuits.

A similar approach to the radio-interference factors is practical. The approach is much more complicated in its broad aspects, however. In the one case, it involved a telephone utility and electric utility working together, or national committees representing the 2 interests, working out a program for investigation and research. In the present problem, equivalent interests are widely scattered and following widely divergent lines.

1. Reliable manufacturers of appliances have given attention to radio-interference effects of their products. In other cases, the same care has not, evidently, been given. A thermostatically controlled fish-aquarium heater selling for about $1.00 has in several instances been found to cause radio interference in neighboring houses. Freedom from radio interference is a general, if not yet universal, indication of merit.

Table I. Classification of Interference Sources

Found by Cincinnati Gas & Electric Company Investigation (1936)

	Per Cent	
Disappeared or unfounded	43.0	
Receiver trouble	18.0	
Ground or antenna	1.0	
Cleared on call or check at receiver		62.0
Loose connection at meter board	4.5	
Refrigerator connection or static conditions	4.5	
Thermostats	1.0	
Miscellaneous appliances	3.5	
Secondary customers' equipment		13.5
Note: $^2/_3$ on complainant's premises, $^1/_3$ in neighborhood		
Street railway equipment	4.0	
Commercial signs	2.0	
Industrial equipment	1.0	
High-frequency equipment	0.5	
Miscellaneous	3.0	
Outside sources other than electric utility		10.5
Loose connections of primary circuits	5.0	
Secondary connections and grounds	2.0	
Loose static wire connections	3.5	
Defective equipment	1.0	
Electric distribution lines and equipment		11.5
Miscellaneous		2.5
		100.0

2. Radio-receiver manufacturers have devoted a great deal of research and experimental work to proper shielding from outside influences. When all these influences are compared to radiobroadcast waves, in field intensity, it may be said a good job has been done. In too many cases, however, careless installations have been allowed to offset these efforts. Further co-operation along this line is in order, to reduce the factor of susceptiveness.

3. In this consideration, the rôle of the electric circuits may be shifted from that of influence to one of coupling. While the primary

lines are most important in the influence field, both in inductive co-ordination and where electric lines cause radio interference, the secondary circuits are usually most important in the coupling effect. It is important to note that secondary circuits include house wiring. Even in cases of exceptionally strong influences, the radio frequency waves do not pass through the impedance of transformers to the primary.

A very important possibility for co-operation in this field includes a workable understanding among the 3 groups in any particular locality, most interested in good radio reception, namely:

(*a*) Radio and appliance commercial group and repairmen.

(*b*) Radiobroadcast technical group.

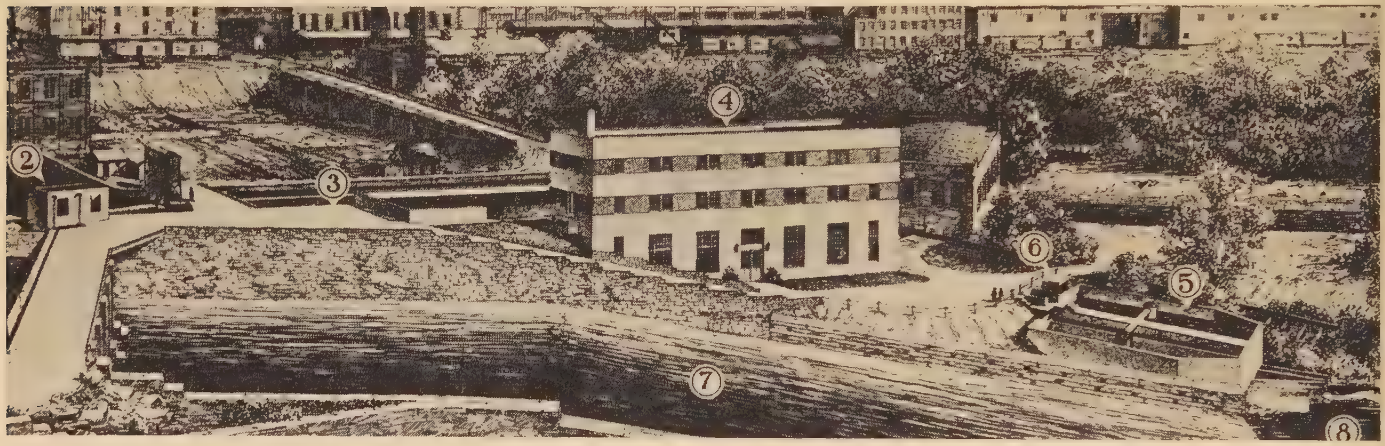
(*c*) Utility distribution engineers and inspectors.

In Cincinnati, where there are 5 broadcast stations, joint efforts of this group and the utility group has led to a procedure for the elimination or alleviation of individual cases of external cross modulation. This information has been put in the hands of all radio service men. Considerable research and field inspection work has been carried on by both groups.

Care is exercised by inspectors on the general and outside influence end, not to step into the field of the service men, whose proper sphere includes correction of any faults in the receiver installation as well as other efforts on the complainant's equipment. On the other hand, there is no attempt to avoid the responsibility of interference elimination when it is caused by outside influences.

There can hardly be a question of the value of joint efforts toward co-ordination of: (1) influence, (2) susceptiveness, and (3) coupling, in the field of electric appliances, radiobroadcast and reception, and electric service. Continued co-operation will lead to control of interference and lessen the need for mitigation and individual corrective measures.

Minnesota Hydraulic Laboratory Being Constructed



NEAR the headwaters of the Mississippi River, 90 miles from its Lake Itasca source, the United States Works Progress Administration is constructing at St. Anthony's Falls a large-scale hydraulic laboratory for the college of engineering of the University of Minnesota. Located on Hennepin Island, in the heart of Minneapolis and near the center of the city's famous milling district, the laboratory will be primarily an experimental and research institution. Its function will be to promote greater knowledge of the use of water power, together with the improvement of hydroelectric machinery, and its facilities will be used by all students studying hydraulics at the University of Minnesota. Reproduced from an artist's drawing of the laboratory as it is expected to be when completed, the figure on this page shows: (2) the intake to the laboratory and the gate-control house; (3) main experimental laboratory for open-channel experiments and river hydraulics; (4) hydraulic machinery and turbine laboratory; (5) discharge measuring basin; (6) wasteway; and (7) tail-water pool.

Because a head of 48 feet is available at the site at all times the location is unusually good for a hydraulics laboratory. A long horseshoe-shaped weir constructed above the falls provides close regulation of head, and facilities are being provided to handle discharges of more than 300 cubic feet of water per second.

The building has been designed to utilize approximately half of the available head for model rivers and other experiments on flow in open channels, the level of the main experimental floor being 20 feet below the main headwater level. The remainder of the drop in the experimental plant permits large-scale volumetric measurements of flow, for which twin basins supplied with pneumatically operated cylinder valves are to be constructed.

The Hennepin Island laboratory is said to be the only one in the United States in which the testing of a full-size turbine will be possible. Its possibilities already have attracted national attention in the field of hydraulics, and experimental work is being planned in co-operation with federal, state, and commercial interests. Much of the research on sediment transportation by rivers being conducted in the University's existing hydraulic laboratory will be transferred to the new quarters when they are completed.

Lightning Strokes in Field and Laboratory—II

By P. L. BELLASCHI
MEMBER AIEE

THE LIGHTNING-STROKE generator has made possible the investigation of lightning-stroke phenomena in the laboratory.[1,2] This paper deals with the fundamental aspect of the problem, particularly with the characteristics of the lightning-stroke channel. The data and findings here presented reveal further the nature of the channel core and of the resulting column.[3] Field observations are also indicated for comparison, to enhance the value of the laboratory investigation.

Test Method

The lightning-stroke generator consists of a high-voltage generator, a heavy-current generator, and a "microsecond switch." A steep-fronted high-voltage impulse from the voltage generator initiates flashover or dielectric breakdown of the test object. Then, within a time measured in microseconds the current generator is switched on thus supplying to the test object a current of lightning-stroke intensity and duration.

A lightning-stroke test is illustrated in figure 2. The voltage generator first breaks down the 36-inch rod-to-plate gap, this occurring on the front which rises at somewhat more than 3,000 kv per microsecond (figure 1*D*). Then, as oscillogram *A* shows, the "microsecond switch" operates and in 5 microseconds the current generator begins discharging across the gap a current which reaches 57,000 amperes and of a total duration of 100 microseconds or more. More rapid and slower follow-up of the current occurs, respectively, for oscillograms *B* and *C*. A lightning-stroke to a distribution-line wood pole appears in figure 9 in which case the voltage to break the pole down rises to 2,500,000 volts, followed by the current of lightning-stroke intensity and duration. These tests are typical of the lightning-stroke testing in this investigation.

Characteristics of Lightning Channel

Tests on Paper and Similar Materials

The results from tests on paper and similar materials are summarized in table I. In these tests a large sheet would be mounted on an insulated wood frame and inserted in the path of the discharge as in figure 2. Test samples indicating the area "blown" are shown in figure 3.

For rather strong, yet quite thin, white paper (first 8 samples), the average area "blown" for a current of 53,000 amperes (average) is close to 0.15 square inch. One test at 23,500 amperes gives an area of 0.07 square inch. On thicker paper (samples 12, 13, and 21) the area is 0.16 square inch for 55,000 amperes. At higher currents, tests on the heavier paper only were possible because of tearing. An area of 0.24 square inch is obtained with 74,000 amperes (samples 15 and 16). The areas "blown" in the paper for currents of 24,000, 54,000, and 74,000 amperes are then, respectively, 0.07 square inch, 0.15 square inch, and 0.24 square inch, that is, the area is proportional to the current of the discharge.

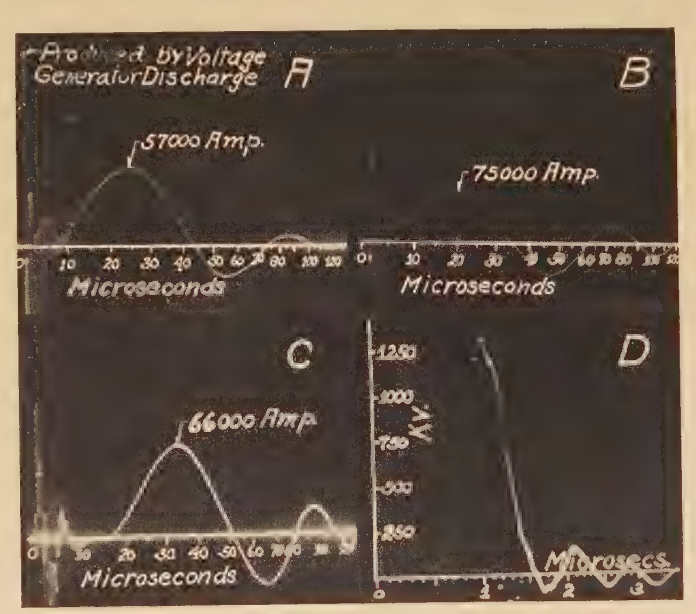


Figure 1. Voltage and current oscillograms of lightning-stroke tests

A blast effect is also present on the specimens. It is in the nature of a surface "erosion" resulting from the combined action of the blast and the associated high temperature. This blast effect extends out radially from the area "blown" and can be seen best on the photograph of the glassine-paper (sample *H* of figure 3), where it assumes a $1^3/_4$-inch diameter at the outer edge. The blast action appears also on the photograph of the discharge in figure 2; here the average diameter of the incandescent column measures close to 3 inches for a current of 55,000 amperes.

Tests were made on tracing cloth. This consists of cloth as a base and a filler material solidly enclosing all interstices between threads. In these tests a dozen small holes are found within a circle of approximately $^1/_2$ inch diameter (sample *G* in figure 3). "Burning" at the surface

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A paper recommended for publication by the AIEE committee on power transmission and distribution. Manuscript submitted March 24, 1937; released for publication July 30, 1937.

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The author acknowledges the assistance in securing the data and in preparing the material for the paper, particularly of the following: Doctor R. C. Mason (Westinghouse Electric and Manufacturing Company) for the derivation in the appendix and other constructive criticism; Doctor M. L. Manning (Westinghouse Electric and Manufacturing Company) for his helpful assistance and criticism; M. Ch. Morel (Switzerland) and J. K. Hodnette (Westinghouse Electric and Manufacturing Company) for specific field data respectively on the core and channel of the lightning stroke; and to the staff of the Sharon high-voltage laboratory for carrying out the tests.

1. For all numbered references, see list at end of paper.

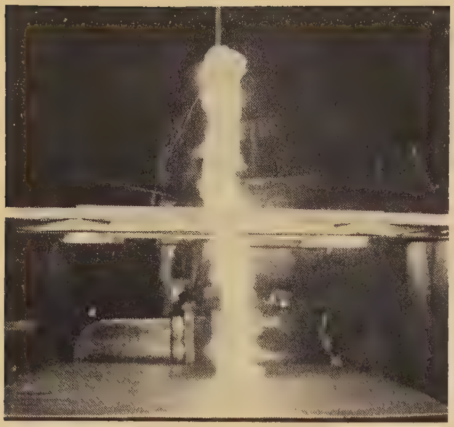


Figure 2. Lightning-stroke discharge through paper sheet

is concentrated within this circle, which indicates that the "core" is maintained here during part of or the whole current discharge then expanding abruptly into the column (figure 2). This explosive expansion of the core into the column is also evidenced from the paper specimens and from the radial tearing of the paper out from the area "blown." It should be noted from the small area "blown" that the current is restricted in its passage through the tracing cloth to some 5 per cent of the area indicated for the core (table I).

The area "blown" in the specimens is generally circular in form, this configuration being even more prevalent for the resulting column. The area "blown" is not always a single hole; at times it would be the combination of a large hole and smaller holes all closely huddled together. The path or paths of breakdown are established by the voltage discharge. The current associated with it, as can be seen from the area "blown" in sample *E* (figure 3), is relatively small compared to the current of lightning-stroke intensity which follows the voltage breakdown (samples *D* and *F*). In 2 cases distinct paths were established, about 10 inches apart, as evidenced from the large "twin" holes of equal size on the specimen (samples I_1 and I_2).

TESTS ON SURFACE OF INSULATION

In these tests the sample was inclined so the discharge would hug the surface (figure 5) leaving thereon a "record." On porcelain the "burning" of the thin glaze, as in figure 4, comprises the record. From table II, the width of the "burning" is $1^{1}/_{4}$ inch for a discharge of 60,000 amperes (average). On photographs the incandescent column measured approximately 4 inches in width. At the center part of the burning in figure 4 the glaze is flaked, this effect indicates that the highest temperature has been maintained there. Away from the center the "burning" becomes progressively less. Upon rubbing the hand along the length of the "burned" surface the flakes are removed leaving a $^{1}/_{2}$-inch "core." In this "core" region the more intense "burning" appears to have been concentrated at the center part within a $^{3}/_{8}$-inch band.

The tests on Micarta gave records on the glossy layer of the surface such as in figure 6. The parts of the record where the discharge hugged the surface are particularly pertinent. They indicate an "inner core" $^{3}/_{32}$- to $^{1}/_{8}$-inch wide and a thinner shell enclosing it, then a sheath or "outer core" $^{1}/_{2}$- to $^{5}/_{8}$-inch on the outside and finally the region of the column extending outward to the total width of $1^{3}/_{4}$ to 2 inches. The explosive action of the "core" into the column is evidenced from the indications appearing on the surface (figure 6) as well as on the photograph of a similar test in figure 5. On the photograph the intense part of the channel is approximately 2 inches; however, the incandescent gases extend out a total width of some 5 to 6 inches. The current in these tests was close to 50,000 amperes.

The "records" in figures 6 and 4, though primarily the result of temperature and bombardment effects on the surface layer, suggest nevertheless that the "core" is apparently a complex of parts and processes. The current varying with time complicates somewhat further the mechanism and structure of the lightning discharge. Even then, without entering into the complex formulation of the detail phenomena which may occur, an estimate of the pressure and temperature in the "core" of the lightning channel should be possible from relatively simple considerations of the experimental findings presented hereto.

The expansion of the "core" from $^{1}/_{2}$-inch diameter or even less to the resulting channel of 3 to 4 inches diameter or more suggests a pressure in the "core" some 40 to 60 times the atmospheric. The corresponding gas temperature in the "core" would then be in the range of 11,000 degrees to 17,000 degrees Kelvin (absolute). These are estimates; for a closer determination, account should be taken in the gas formula of the process of expansion such as the turbulent interaction of incandescent gas and air (see photographs), the recombination into molecular form of the atomic elements, the positive and negative ions, besides other effects.

From a consideration of the electromagnetic force on

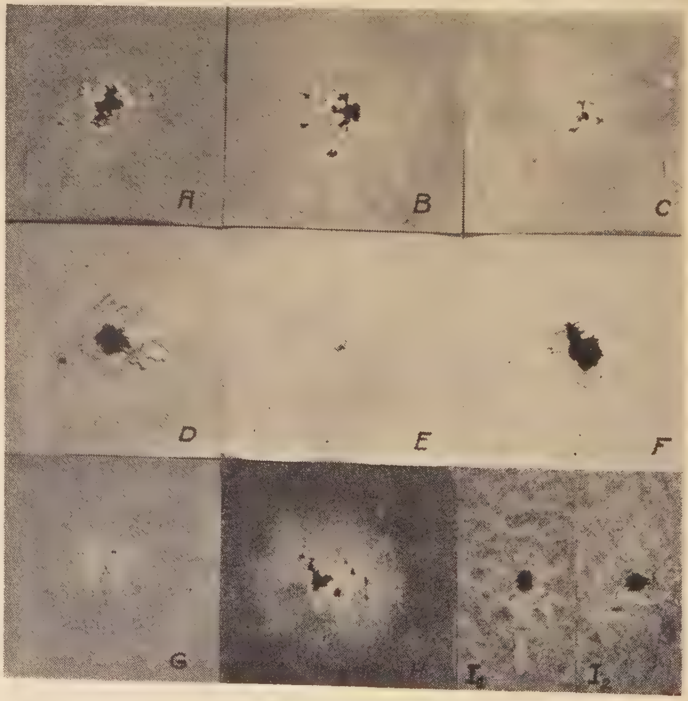


Figure 3. Area "blown" in paper and similar materials (see table I)

the current elements (the electrons comprise the bulk of the current flow), a further approach may be obtained on the internal pressure and whether this compression force accounts in part or all for the balancing of the gas pressure in the core. Both the circular form of the core and its abrupt expansion as the current ceases to flow are consistent with the rôle of the electromagnetic force balancing the gas pressure in the core during the current flow. Considering a current I (abamperes) uniformly distributed in a core R centimeters in radius, the "electromagnetic pressure" at x centimeters from the center is (see appendix)

$$P = \frac{I^2}{\pi R^2}\left(1 - \frac{x^2}{R^2}\right) \text{ dynes per square centimeter} \qquad (1)$$

The deduction of interest from equation 1 is that the electromagnetic force can account for a pressure on the current elements (electrons) in the order of the estimated gas pressure and thus appears as a major factor in balancing the gas pressure in the core. The "electromagnetic pressure" is applied directly to the electrons as these comprise the bulk of the current flow. Furthermore, the "electromagnetic pressure" decreases with increasing distance from the core center so other processes both internally and at the surface of the core play a part in the general equilibrium of forces, charges, and matter. Attempts to analyze rigorously these processes have been made[4] and in this connection the experimental data presented in the paper should be a guide to such theoretical analyses.

From a consideration of the large force acting on a relatively small mass, the time for the core to expand into the column estimates to be in the order of microseconds. The large impact resulting from this expansion explains the concussion experienced by persons that have been hit or were within a few feet of the lightning discharge. This explosive action likewise explains the detonation or thunder produced by lightning, either in the field or in the laboratory.

Negatives of Photographs

The lightning discharge, when analyzed from the photograph negatives, appears as a white streak (the core) surrounded by a dark sheath (the resulting column), such as shown in a measure in figures 7 and 8. These are, respectively, photographs of the negatives of figures 2 and 5. The white streak is about one inch wide, the more intense part is $^1/_2$ inch or less. This intense part comprises the core proper where the temperature is highest and maintained longer.

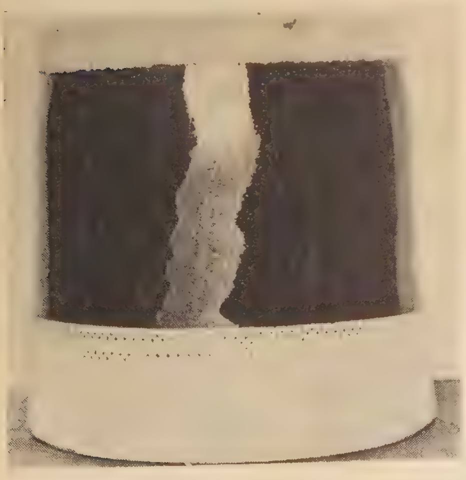


Figure 4. "Record" on glaze of porcelain (see table II)

The negatives indicate some expansion of the core proper, partly perhaps due to the variation of the current during the discharge, besides a natural expansion, and in part possibly due to the apparent photographic effect of the high temperature of the core. The abrupt or explosive expansion of the core into the column is also indicated on the negatives. The temperature of the gases appear to suffer a considerable reduction with this expansion. A determination of the relative or absolute temperature in the core and in the resulting parts of the channel may be possible from further study of the effects appearing on negatives.

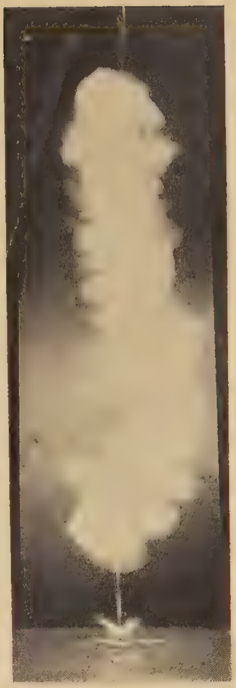


Figure 5. Lightning-stroke discharge on Micarta surface

Tests on Wood Poles and With the Rotating Camera; Deionization of Lightning Channel

Not all poles struck by lightning are damaged, for as long as the discharge is external of the pole, relatively small splintering results. When the discharge is internal, as in a seasoned crack (figure 9), then the pole is generally badly damaged (figure 10) due to the explosive force of the core. In the photograph of figure 9 the source of light for the exposure came from the flash of the core and from the incandescent column which persists for some time after the discharge. Figure 10 was taken after the test and shows fully the resulting damage to the pole. From these and similar other photographs it is amply apparent that the mechanical effects produced by lightning are impulsive in character.

In the process of the shattering of the pole, a force F is applied to the wood mass m for a time t. A part of the momentum

$$\int F\,dt$$

is consumed to "blow out" the wood mass; the remaining momentum mv imparts motion v to the wood mass. Considering the relative magnitude of force F and considering the time t with mass m of the wood blown as indicated in figure 10, even though the momentum

$$\int F\,dt$$

were consumed largely in imparting motion alone, some hundredths of a second appear necessary to displace the mass of wood blown a few centimeters away from the

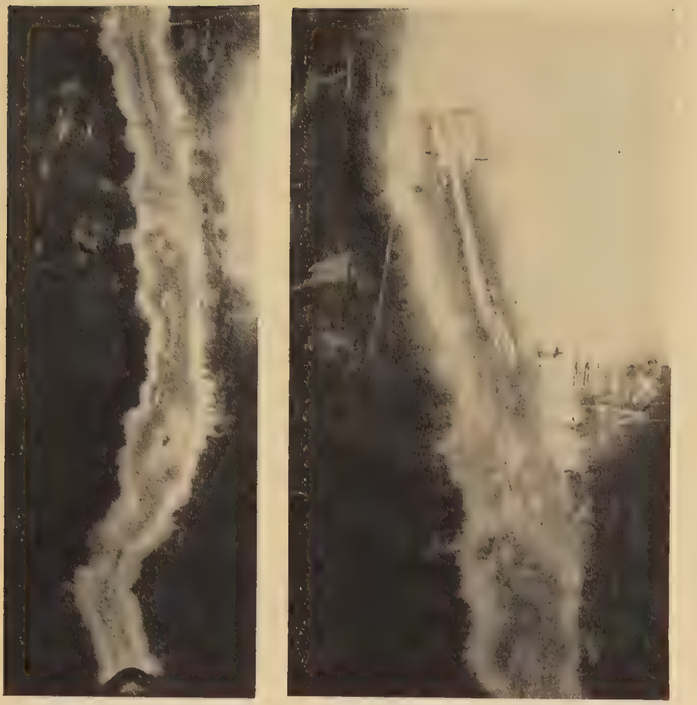


Figure 6. Surface effect on Micarta indicating character of lightning channel (see table II)

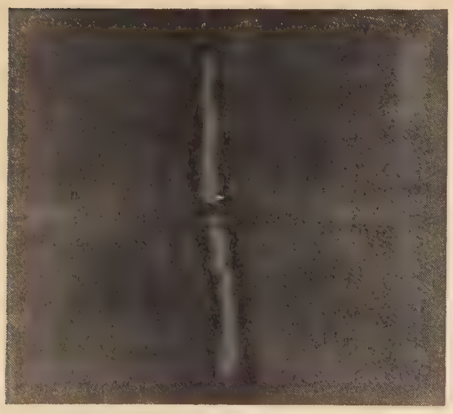


Figure 7. The lightning channel from negative of figure 2

pole proper as shown in figure 9. It can be seen then from the relatively small displacement of the wood blown during the time the column is incandescent (figure 9) that the lightning channel remains ionized for some hundredths of a second and more.

To establish more fully the deionization process of the lightning discharge, photographs were recorded with a rotating camera. The camera employed consists of a fixed lens and a 10-inch diameter circular film rotating one revolution in 0.02 second. A photograph of the discharge between the rod and plate (figure 2) is shown in figure 11*A*. In this test the lens is approximately 7 feet from the discharge. The voltage discharge appears first, followed in 15 to 20 microseconds by the indication of heavy current. The column is particularly intense during the first 50 microseconds due to the heavy current discharge (figure 1). It remains relatively intense for some 300 microseconds, diminishing continuously to a much reduced intensity at 0.002 second. Only a faint trace remains on the negative at 0.005 second. Incandescence at the electrode ends persists longer but all traces of incandescence in the column completely disappears in 0.01 second.

Two other photographs are shown in figure 11*B* and *C*. In these tests the camera was moved closer to the arc and the lens was opened wider, so naturally these records are more intense throughout than the first one. All 3 records indicate essentially the same process of deionization. The combined results of 8 records establish that incandescence of the channel completely disappears in 0.01 to 0.02 second after the lightning-current discharge. Therefore, the path of the lightning discharge reaches an advanced stage of deionization in this order of time.

Tests on Fiber Tubes and Metal Surfaces

Tests on fiber tubes were briefly reported in the first paper.[3] The tubes were from 2 to 3 feet in length and $^{1}/_{4}$ to $1^{1}/_{4}$ inches inside diameter. Wall thicknesses ranged from 0.2 to 0.6 inch. Lightning currents from 100,000 to 130,000 amperes and of some 200 microseconds duration to one-half value were discharged through the tubes. In these tests the discharge was initiated with a fine copper wire. It was found that the tubes would discharge these severe lightning currents without shattering when the internal diameter of the tube exceeded approximately $^{3}/_{4}$ inch. For the smaller diameter tubes shattering would result but even then the ends of the thicker tubes remained intact for several inches. These tests suggested the relatively small size of the core and the explosive action produced from its expansion.

Tests comprised of discharging a current by a fine copper wire (0.08 in diameter) to the center of smooth copper plates were then conducted. A very small hole was bored at the center of the plate to carry the fine wire straight through. The averages from 10 tests are summarized in table III. These tests indicate that the area of the surface "fused" by the discharge is proportional to the current. A core of 0.60 inch in diameter is indicated in figure 12 for a current discharge of 134,000 amperes. The column resulting from the explosion of the core measured from 4 to 6 inches in diameter on photographs. A close examination of the fusion in figure 12 indicates that the fused metal on the surface is beaded quite uniformly with some grading on approaching the edge of the circle. The beads covering the center part of the circle are somewhere in the order of a hundredth of an inch. The surface fusion terminates quite abruptly at the edge

Figure 8. The lightning channel from negative of figure 5

of the circle. These observations confirm further that the core is sustained for the greater part of the whole duration of the current discharge and they also indicate some expansion or variation in the size of the core. A series of concentric regions appear just beyond the core circle. These apparently indicate a uniformly circular expansion of the gases in the initial stages and they suggest from the graded colors of the copper oxide the relative temperature drop. The irregular "blotches" of oxidized surface beyond these concentric regions confirm that in the later stages of the abrupt expansion of the core into the column, the expansion process is of a turbulent character.

Table I. Effects Produced by Lightning Discharging Through Paper and Similar Materials*

Sample Number	Material	Lightning Current** (Amperes)	Area "Blown" in Sample by Discharge (Square Inches)	Diameter of Blast Visibly Indicated on Surface of Sample (Inches)	Comments
1	White paper 0.0025 inch thick	47,000	0.18	$1^1/_2$	See figure 3*A*
2		55,000	0.16	$1^1/_2$	See figure 3*B*
3		56,000	0.18	$1^1/_2$	Two large holes and few smaller ones grouped together within 1-inch-diameter circle
4		50,000	0.14	$1^3/_4$	One large hole and 2 smaller ones adjacent
5		23,500	0.07	1	See figure 3*C*
6		53,000	0.11	$1^3/_4$	One large hole and smaller one adjacent
7		55,000	0.13	1 (approximately) corresponding to each group	Two groups of holes 9 inches apart
8		55,000	0.12	$1^1/_4$	Two large holes and few smaller ones grouped together within 1-inch-diameter circle. See figure 2
9, 10, and 11		57,000, 69,000, and 82,000	Samples torn	$1^1/_2$, $1^3/_4$, and 2	Samples torn 1 to 3 inches radially out from area "blown"
12	Light brown paper 0.0075 inch thick	54,000	0.16	$1^1/_2$	See figure 3*D*
13		54,000	0.18	$1^1/_2$	One large hole and small one adjacent
14			0.003		Voltage only applied. See figure 3*E*
15		75,000	0.24	$1^1/_2$	See figure 3*F*
16		73,000	0.23	$1^1/_2$	One large hole and smaller one adjacent
17	Tracing cloth 0.0035 inch	54,000	0.01	$1^1/_2$ (center part within $^5/_8$-inch circle heavily burned)	A dozen small holes within $^5/_8$-inch-diameter circle. See figure 3*G*
18		54,000	0.01	Center part of each group heavily burned within $^1/_2$-inch circle	Two groups of 6 and 10 small holes $1^1/_2$ inches apart
19	Glassine paper 0.0015 inch thick	56,000	0.08	$1^3/_4$	Group of 7 holes within 1-inch-diameter circle and 8 (smaller) holes further out. See figure 3*H*
20		56,000	0.09	$1^3/_4$	Sample torn 1 to 3 inches radially out from area "blown"
21	Wrapping paper 0.007 inch thick	57,000	0.14	1-inch diameter (approximately) corresponding to each hole	Two large holes 10 inches apart. See figure 3 (I_1 and I_2)
22	Cotton cloth 0.005 inch (light brown)	56,000			Faint indication of singeing

* For test set-up see figure 2.

** (*a*). Wave form of current for tests on samples 1, 2, 3, 4, 6, 7, 8, 12, 13, 17, 18, 19, 20, 21, and 22 given in figure 1*A*.

(*b*). Wave form of current for tests on samples 9, 10, 11, 15, and 16 given in figure 1*B*.

(*c*). Wave form of current for test on sample 5 is aperiodic, rising to crest in some 7 microseconds and receding close to zero in 60 microseconds.

(*d*). In the tests on samples indicated in (*a*) and (*c*) the spacing between the rod and plate (see figure 2) was 36 inches with the sample 14 to 17 inches from the plate. In the tests on samples indicated in (*b*) and for sample 14 the spacing between rod and plate was 18 inches with the sample 10 inches from the plate.

(*e*). In the test on sample 14 the voltage generator alone discharged. The current associated with the voltage generator discharge is relatively small in amplitude and duration compared to the lightning currents (column 3).

(*f*). The voltage initiating breakdown of the 36-inch gap is shown in figure 1*D*.

FIELD RECORDS COMPARED WITH LABORATORY DATA

Considerable field data on lightning[11-24] are now available but observations bearing on the lightning stroke channel are rather limited yet. A few typical instances will be considered for comparison with the laboratory data.

Holes have been "blown" in windows by lightning. In one case[5] the hole was in the order of a couple centimeters. The edges of the hole were melted. Two interesting observations have been reported recently to the writer by M. Ch. Morel (see also references 6 and 7). In these 2 instances the holes "pierced" in window panes measured in one case 4 centimeters and in the other 2 centimeters approximately. In a report on airplanes hit by lightning,[8] holes the size of a penny, or larger ones where the fabric would be torn, were found. Fulgurites in dry sand are described[5] that take "the shape of vertical tubes which may be nearly half an inch in diameter and several feet long. Externally they are rough somewhat whiter than the surrounding sand; inside they are enamel-like, from the glassy surface of fused silicon." Rock blasted by lightning indicates a fusion streak some one-half inch wide marking the path of discharge. These experiences alone show good agreement on the size and general characteristics of the core of the lightning strokes in the field with the corresponding though more complete measurements in the laboratory.

The explosive character and damaging effects of lightning discharges are well known.[3,6,7] Wood poles splintered by lightning evidence the same character of damage and explosive effects as have been found from the laboratory tests.

The size of the lightning-stroke channel has been measured from photographs or estimated from visual observation. Considering the heaviest lightning flash, Walter estimates[9] by photographs the breadth of the channel to be only 10 centimeters. In one case recently

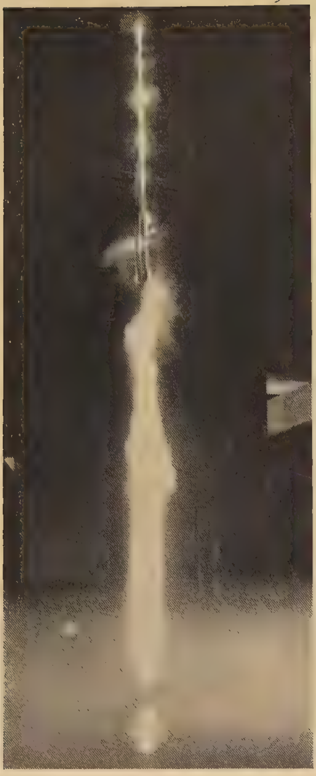


Figure 9. Lightning stroke to distribution-line wood pole

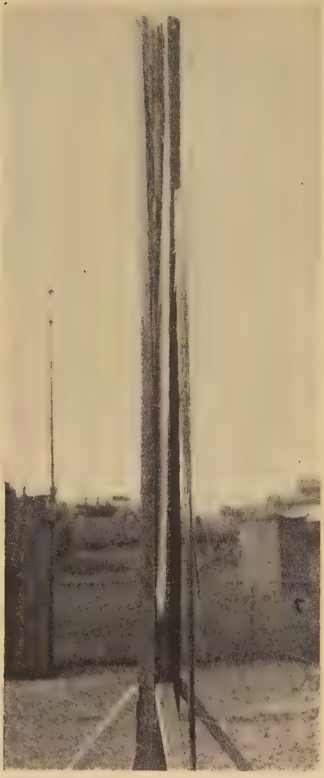


Figure 10. Resulting damage of wood pole from test in figure 9

called to the writer's attention, the observer was at about 50 feet in direct line of vision from a tree struck by lightning. Number 18 copper wire was hanging from midway of the tree to several feet above ground. Lightning splintered the top of the tree, following the copper wire then to ground. The current in this stroke is estimated to not exceed 50,000 amperes, since the copper wire was fused in segments but not completely volatilized.[10] The size of the channel by comparison to the trunk of the tree was estimated at 15 to 20 centimeters. Even these few cases are quite indicative that the dimensions of the lightning channel observed in the field are comparable to those measured in the laboratory.

A recent contribution by Doctor B. F. J. Schonland has come to the author's attention entitled: "The Diameter of the Lightning Channel," *Philosophical Magazine*, series 7, page 503, March 1937. A photograph of a lightning flash consisting of 11 discharges is discussed therein which shows the first and last separate strokes of the discharge to have had their channels shifted a distance exceeding 3.7 meters by the wind. It is found that the average diameter of the lightning stroke channel is about 16 centimeters. The heaviest stroke gave a diameter of 23 centimeters and the weakest branch one of 11 centimeters.

Summary

1. The lightning-stroke effects on paper, tracing cloth, porcelain, Micarta, and photograph negatives indicate an area (circular) for the core proportional to the current in the lightning discharge. This apparent area is, respectively, 0.08, 0.16, and 0.24 square inch for currents of 25,000, 50,000, and 75,000 amperes. Tests on fiber tubes at 140,000 amperes indicate an area of 0.44 square inch.

2. The surface fusion on copper plates, the photograph negatives, the glaze burning on porcelain, the record on Micarta, and other effects all show that the core is sustained the greater part of or the whole duration of the lightning-current discharge. The center part, some two-thirds or one-half, of the above-mentioned area comprises the core proper where the temperature is highest and maintained longer. Some expansion or variation in the core proper takes place during the discharge apparently resulting in the larger area. The actual current in the discharge (electrons for the greater part) naturally occupies but a fractional part of the core. The above records and observation suggest that the core structure is a complex of parts and processes.

3. When or as the current ceases the core then expands abruptly or explodes into the column. The expansion appears from the records relatively uniform (circular), the gases suffering a corresponding temperature drop with expansion. The later stages of the expansion process be-

Table II. Effects Produced by Lightning Discharging Along Surface of Insulation Materials*

Sample Number	Material	Lightning Currents** (Amperes)	Diameter of Center Part Indicative of Concentration of Discharge (Inches)	Diameter of Blast Visibly Indicated on Surface of Sample (Inches)	Comments
23	Porcelain tube $9^1/_2$ inches high, $9^1/_2$ inches diameter, $^1/_2$ inch thick (see figure 4)	58,000	$^1/_2$	$1^3/_8$	Length of discharge along the glazed surface along height = 5 inches. See figure 4 which shows effect of discharge
24		57,000	$^1/_2$	$1^1/_4$	
25		58,000	$^1/_2$	$1^1/_4$	
26		66,000	$^5/_8$	$1^1/_2$	
27	Fullerboard 9 by 17 inches, $^5/_8$ inch thick	64,000	Center part not outstanding	$2^1/_2$ (average)	Length of discharge = 10 inches
28	Micarta panel 12 by 30 inches, $^1/_4$ inch thick	51,000	Inner "core" $^3/_{32}$-inch-diameter. Outer "core" $^5/_8$-inch-diameter	$1^3/_4$ (average)	Length of discharge = 20 inches. See figure 6 for effects of discharge

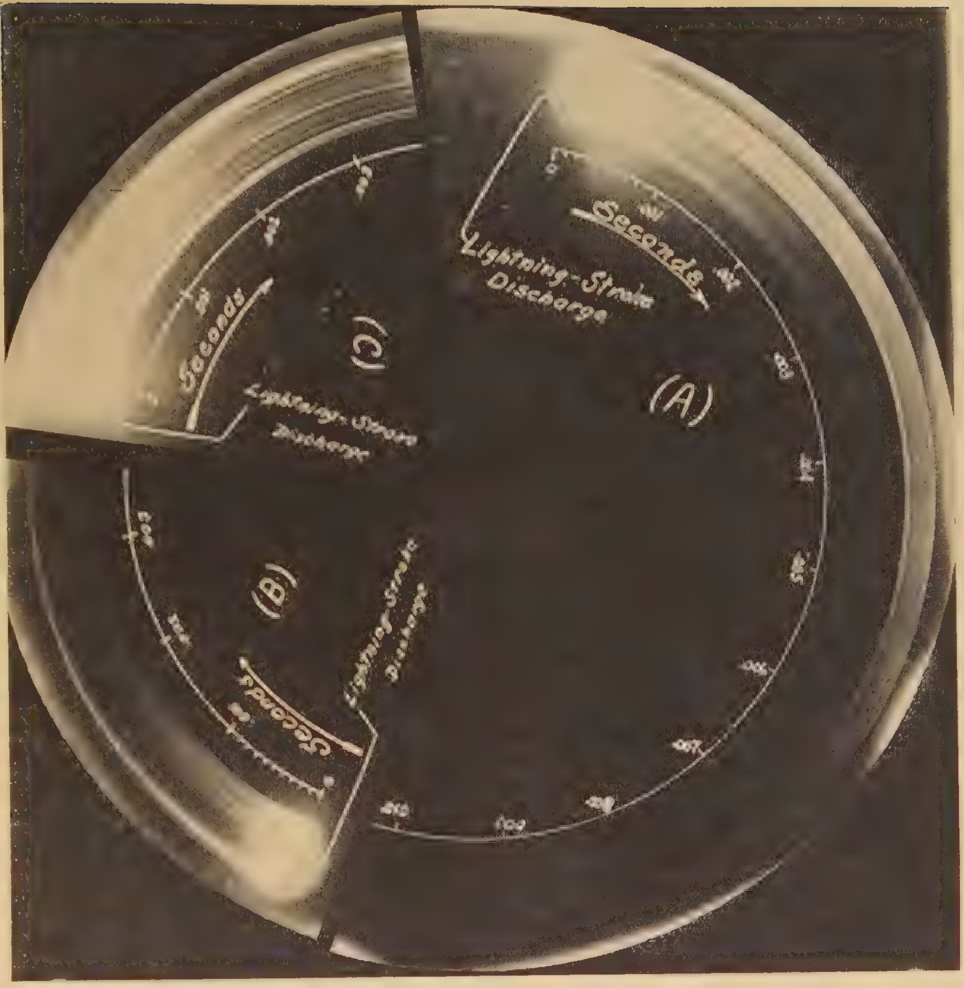
* Typical test set-up shown in figure 5.

** (*a*). Wave form of current for tests on samples 23, 24, 25, 26, and 27 given in figure 1*C*.

(*b*). Wave form of current for test on sample 28 similar to figure 1*C* except period is 20 per cent longer.

come turbulent in character. Thus for a current discharge of 50,000 amperes, uniform expansion apparently extends some one to 2 inches in diameter. Turbulent action then follows and the totally expanded incandescent column (measured on photographs) approximates a 3-inch diameter. For a current discharge of 140,000 amperes the incandescent column measures on photographs 4 to 6 inches in diameter.

4. The expansion of the core into the size of the channel suggests a pressure in the core some 40 to 60 times the atmospheric and a corresponding gas temperature in the range of 11,000 degrees to 17,000 degrees Kelvin (absolute). A more rigorous determination would require that account be taken of the turbulent interaction of the expanding incandescent gas with the surrounding air, the recombination of disrupted elements and ions (positive ions and electrons) into molecular form, besides a consideration of the complex core structure and other effects.



Seconds
Lightning-Stroke Discharge
(A)
Seconds
Lightning-Stroke Discharge
(B)
Seconds
Lightning-Stroke Discharge
(C)

Figure 11. Photographs of lightning flash with the rotating camera to determine duration of incandescence (deionization of lightning path)

5. The electromagnetic force produced by the current can account for a pressure on the current elements (electrons) in the order of the estimated gas pressure deduced from the expansion. Thus the "electromagnetic pressure" (directed centrally inward) appears as a major factor in balancing the gas pressure in the core (directed outward). Other processes both internally and at the surface of the core play a part in the general equilibrium. The experimental data and findings presented in the paper offer the basis for more extensive theoretical analysis.

6. From a consideration of the large force acting on the relatively small mass of the core, the time for the core to expand into the column is estimated to be in the order of microseconds. The experimental findings confirm the estimate. The large impact resulting from the expansion accounts for the concussion experienced by persons that have been hit by or were within a few feet of the lightning discharge. This explosive action likewise explains the detonation or thunder produced by lightning.

7. The shattering of wood poles and similar destructive effects show that the mechanical forces and impact produced by lightning are impulsive in character. It can be deduced from these tests and the corresponding photographs that the lightning channel remains incandescent (ionized) for some hundredths of a second.

8. Records of the lightning flash with a rotating camera establish that the lightning path is particularly intense during the current discharge (50 to 100 microseconds). The established channel remains relatively intense for some 300 to 500 microseconds, diminishing continuously to a much reduced intensity in about 0.002 second. The results of 8 records establish that incandescence of the channel completely disappears in 0.01 to 0.02 second after the lightning-current discharge. Therefore, the path of the lightning stroke reaches a stage of advanced deionization in this order of time, a finding well in accord with the field data on the time interval between repetitive strokes.

9. The field records and data on the core and channel of the lightning stroke, though relatively few, indicate general accord with the more extensive laboratory findings here presented.

Appendix

The derivation of equation 1 is based on the following fundamental consideration: To be in equilibrium the pressure gradient

$$-\frac{\partial P}{\partial x}$$

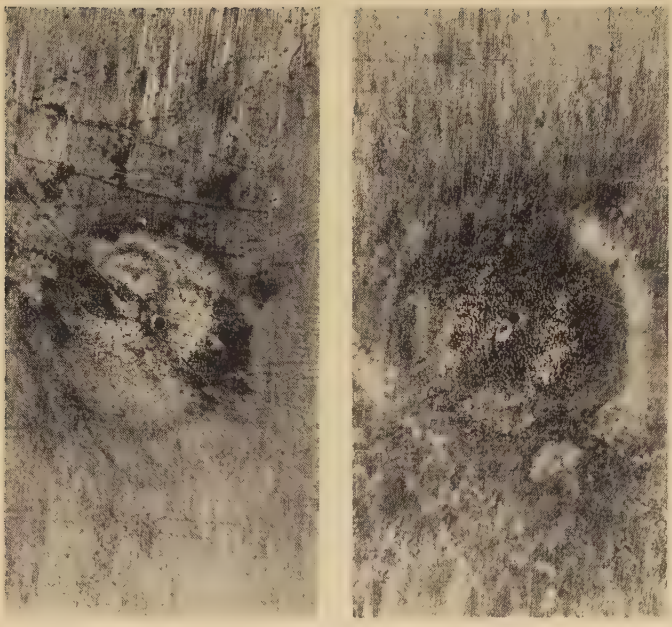


Figure 12. Surface "fusion" on copper plates indicating nature of core and resulting channel of lightning stroke (see table III)

Table III. Surface Fusion Produced by Lightning Discharge to Polished Copper Plates

Number of Samples	Lightning Current	Diameter of Core (Inches)	Diameter of Blast Indicated on Surface (Inches)
Four	134,000	0.61	1 1/2
Two	105,000	0.51	1 1/8
Two	79,000	0.46	1

at any point x must balance the volume forces acting on the gas. The equation is derived elementarily by considering a shell of the core of radius x centimeters and thickness dx. The current I (abamperes) is considered uniformly distributed in the core of R centimeters in radius.

The magnetic force (volume force) on the shell per centimeter length is the product of the magnetic field at x and the current in the shell, i.e.,

$$2\Delta\pi x \cdot \Delta 2\pi x dx$$

where

$$\Delta = \frac{I}{\pi R^2}$$

is the current density.

The force on the shell due to variation in gas pressure balances the magnetic force, so

$$-\frac{\partial P}{\partial x} 2\pi x dx = 2\Delta\pi x \cdot \Delta 2\pi x dx$$

$$-\frac{\partial P}{\partial x} = 2\Delta^2\pi x$$

i.e., pressure gradient equals volume force. Then,

$$p = -\Delta^2\pi x^2 + \text{constant}$$

From the boundary conditions $p = 0$ when $x = R$, thus making p merely excess over atmospheric pressure at the outer boundary of the core,

$$p = \Delta^2\pi R^2\left(1 - \frac{x^2}{R^2}\right)$$

or since $\pi\Delta R^2 = I$, equation 1 is obtained:

$$p = \frac{I^2}{\pi R^2}\left(1 - \frac{x^2}{R^2}\right) \text{ dynes per square centimeter} \qquad (1)$$

At $x = 0$

$$p_{(\max)} = I\Delta$$

Substituting the experimental data of a core section 0.15 square inch for 54,000 amperes, then

$$p_{(\max)} = \frac{5400 \times 5400}{6.45 \times 0.15} = 30 \times 10^6 \text{ dynes per square centimeter}$$

or about 30 atmospheres.

Even at $\frac{x}{R} = 0.9$, $p = 30\,(1–0.81) \cong 6$ atmospheres.

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A System Out of Step and Its Relay Requirements

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MEMBER AIEE

Synopsis

This is a study of the current, voltage, and power values throughout a simple transmission system when machines are operating out of step. The investigation was made to determine the proper relay protection for some large frequency changers which supply power to an electrified railroad. The object was to find means for protecting machines that had already fallen out of step or, if possible, to prevent them from falling out due to overload.

The treatment of the problem is geometric, probably the easiest method to comprehend. The assumed conditions have been kept as simple as possible, but it is hoped that the method of treatment is complete enough to permit anyone interested in the subject easily to apply it to more complex problems. It is to be particularly observed that the common method of assuming that a system consists of pure reactance leads to errors that are noticeable on 25-cycle systems where the reactance is low.

As a by-product of the study of machine protection, it was discovered that the behavior of different types of line-sectionalizing relays under out-of-step conditions can be easily predetermined and proper adjustments made to obtain a more desirable performance of such relays.

Two Machines Fall Out of Step

WHEN A GENERATOR and a motor are connected together and the motor is loaded, the generator poles advance and the motor poles retard, the angular difference being a measure of the power transfer. This angular difference produces a flow of current which tends to keep the 2 machines in step. The accompanying series of small sketches show what happens as the motor pole lags farther and farther until it is definitely out of step and until it comes back into step again after completing one full revolution, that is, after it has slipped 2 poles. The sketches shown in figures 1*A* to 1*J* form a sort of primer on the elementary conditions which exist when 2 machines are out of step. Figure 1*A* shows that if the motor poles lag behind the generator poles, the voltage which induces interchange of current between the 2 machines is $E_G - E_M$. These voltages are generated voltages and are not the quantities which are ordinarily measured at machine terminals. Figure 1*B* shows that the voltage difference between the 2 machines is the greatest when the poles are 180 degrees out of phase but as the motor continues to lag behind the generator, it comes back into step with the next pole as shown in figure 1*C*. Whether or not the motor will slip another pair of poles in the same manner depends upon the conditions existing in the system. The resultant voltage, as shown in figure 1*D*, increases from a zero value when the poles are exactly in step to its maximum when they are 180 degrees out of step and back to zero again following a circle as a locus. As will be observed, the shift in phase angle of this resultant does not go through a 360-degree cycle but only through 180 degrees. Also at the start and at the finish position the voltage value is zero. Since a complete slip

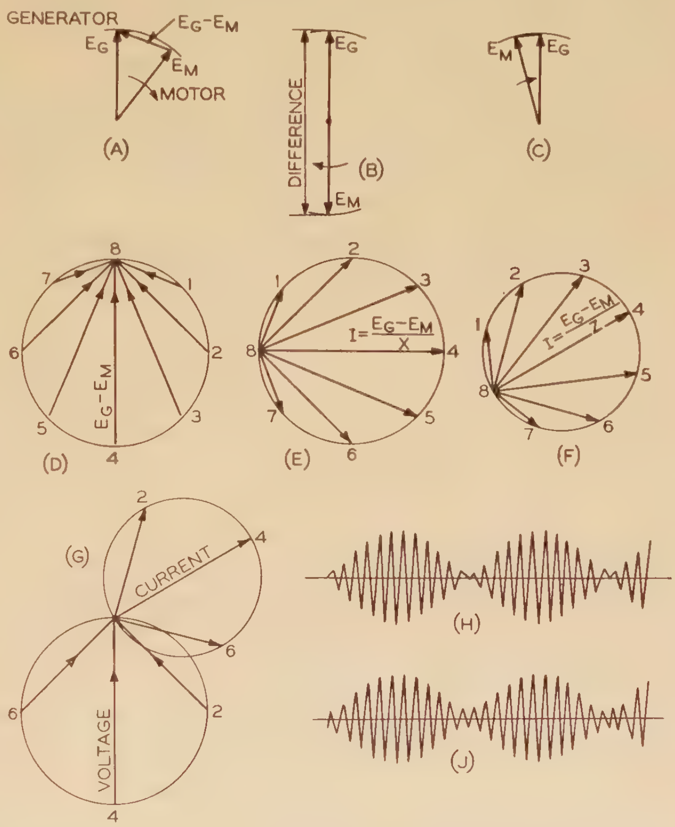

Figure 1. Two machines out of step

A—As the motor lags, the voltage difference increases until—

B—it reaches a maximum when the poles are 180 degrees out of phase

C—As the lagging pole continues around the circle, the difference approaches zero again

D—The voltage ($E_G - E_M$) moves around this circle through a complete cycle of 180 degrees

E—The current that flows between the 2 machines is at right angles to the voltage (resistance neglected)

F—Resistance in the circuit decreases the current and tilts the axis of the circle

G—The combined diagram

H—The current surges if the machines have equal excitation

J—If the excitations are unequal

A paper recommended for publication by the AIEE committee on protective devices. Manuscript submitted August 2, 1937; released for publication August 27, 1937.

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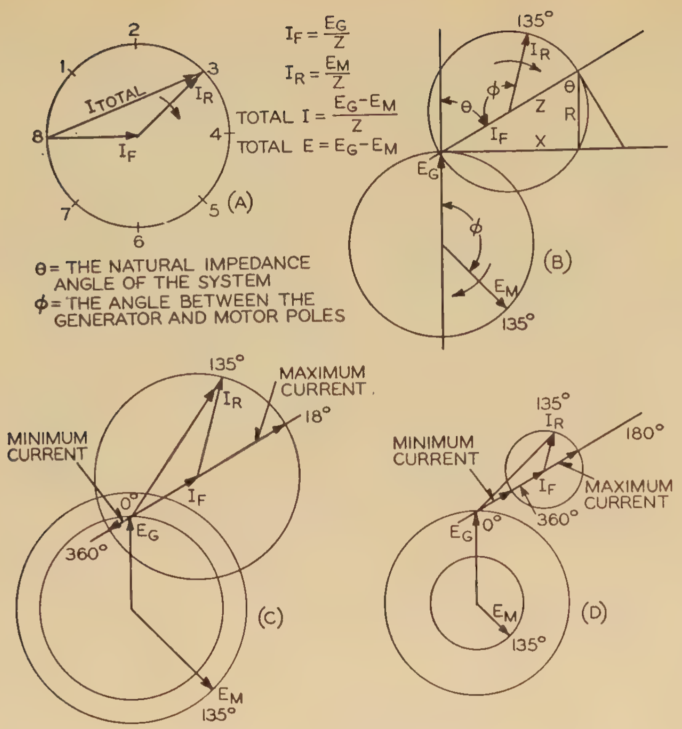


Figure 2. Analysis of the current through the system and the voltage difference between the generated voltages at each end of the line

A—A current or voltage vector oscillating through 180 degrees may be resolved into 2 components, one fixed and the other rotating through 360 degrees in step with the slipping pole

B—This is another way of representing figure 1*G*. $E_G = E_M$

C—If the generator and motor voltages are not equal, the current will never become zero. Here the motor voltage is higher

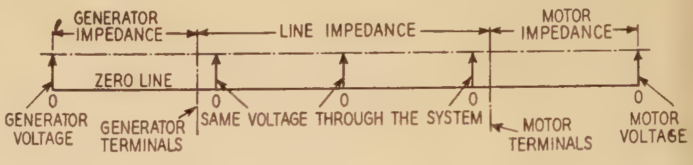
D—Here the motor voltage is lower and the difference greater, hence the minimum current is greater

cycle of 360 degrees of the poles results in a shift in phase in the resultant voltage of only 180 degrees, confusion will be avoided by applying the angle in degrees always to the slip of the poles. In the figures the pole slip is also shown in positions, 1, 2, etc., so that simultaneous current and voltage vectors can be readily compared.

The behavior of the current is the same as that of the voltage except that the current lags behind the resultant voltage by an angle determined by the natural power factor of the system. This angle is the same as the angle which the current lags behind the generated voltage under short-circuit conditions. In figure 1*E* the current is shown lagging 90 degrees behind the voltage. This, of course, cannot exist in practice, although there are some generators where the short-circuit current can lag as much as 88 degrees. In figure 1*F* is shown the conditions in a system having an angle of 60 degrees. It will be convenient to use these 2 angles, namely, 60 and 90 degrees, for purposes of illustration throughout this discussion.

The current locus and the voltage locus for a 60-degree system are combined in figure 1*G* to show that the angle between the current and the voltage is the same, throughout all points of the slip cycle, although their values vary from zero to zero. The current surge, which occurs in the system under out-of-step conditions, is shown in figure 1*H*. These are the values shown in figures 1*E*, 1*F*, and 1*G* and is a similar picture to that given by the ordinary oscillogram taken on a system which is out of step. This is also the shape of the voltage pulsation through the system, but does not represent the voltage between wires or across the terminals of any machine. For purposes of comparison, a current surge in figure 1*J* is given to show what happens if the excitation of the 2 machines is unequal. This will be explained later.

In order to analyze more thoroughly the conditions throughout a system consisting of 2 machines at each end of a transmission line, it is convenient to separate the current and voltage vectors into 2 components. For example, $E_{(\text{total})} = E_G - E_M$. Here E_G is a fixed quantity and E_M is a rotating vector. It will, therefore, be convenient at other places on the system to refer to the voltage between wires as $E_{(\text{total})} = E_F - E_R$ where E_F is a fixed and E_R is a rotating vector. Similarly, the current vector, as shown in figure 2*A*, can be resolved into 2 components and $I_{(\text{total})} = I_F + I_R$. It will be observed that the voltage vector is a difference of 2 components and the current vector a sum of 2 components. As will be shown later, this means that at any particular point on a system the current value is a maximum when the voltage between conductors is a minimum. In figure 2*B* the the quantities that were previously shown in figure 1*G* have been broken up into their 2 components. There are, therefore, 2 voltage vectors and 2 current vectors or a total of 4 quantities instead of a total of 2 quantities. A reason for doing this becomes immediately apparent in the next figure.



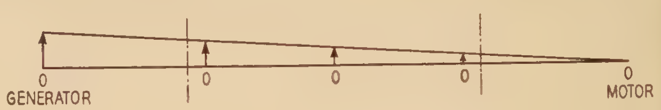


Figure 3 (top). Machines in step—no load—equal excitation

Figure 4 (bottom). Motor without excitation, showing the impedance drop in the system

In studying out-of-step conditions the effect of changes in field strength is usually of primary importance. In figure 2*C* the generator and motor voltages have been laid out, and corresponding values of I_F and I_R have been added to the diagram. The value of these vectors has been determined from the equations given in figure 2*A*. It will be observed that the locus of the current does not go through the zero point. This is because the 2 generated voltages are unequal. The interpretation of this is easily made—the machine having the greater field strength (in this figure, the motor) supplies a constant magnetizing current to the other machine. This is probably more easily understood in figure 2*D* where the motor voltage is less than the generated voltage and consequently the ro-

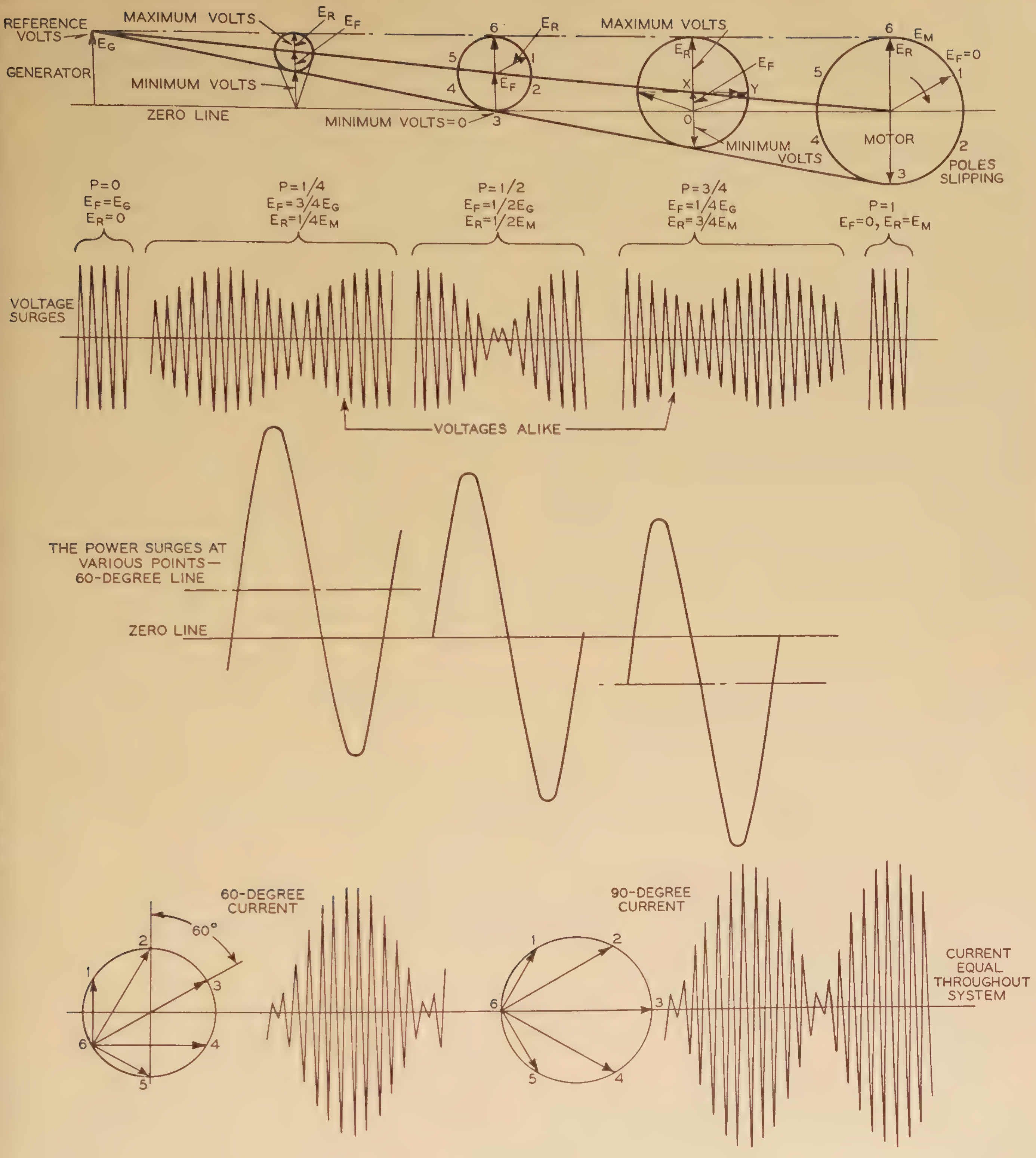


Figure 5. The voltage, current, and power surges on a system where the generator and motor voltages are equal

tating current vector less than the fixed vector. The conditions shown in both figures 2*C* and 2*D* produce a current surge such as that shown in figure 1*J*.

A study of figures 1 and 2 has shown the following conditions to exist:

1. The flow of current between the machines is not a sinusoidal pulsation but it varies from zero to zero through only 180 degrees.

2. The same thing is true of the voltage difference between the 2 machines.

3. Each of these variables can be resolved by geometric methods into a fixed component and a rotating component. The fixed current component is dependent on the fixed voltage component and likewise the rotating current component is determined by the rotating voltage.

4. If there is assumed to be no resistance in the circuit the current vectors will be 90 degrees behind their respective voltages. Resistance in the circuit will decrease this angle and also decrease the magnitude of both the current components.

5. A change in generated voltage of either of the machines affects

the value of the fixed or the rotating current and voltage vectors. This is the factor which must be given particular consideration when studying the protection of machinery because it is most likely to affect some of the protective methods which have been considered in the past.

It should be borne in mind that the voltages shown in this series of sketches (figures 1 and 2) are internal generated voltages. These will differ from terminal voltages or voltage values available out on the line in the manner shown in the second series of diagrams.

Two Machines With a Transmission Line Between Them

The series of vector diagrams, figures 3 to 6, showing what happens on this simple system is useful because it can be applied in different ways. By way of illustration, some of the figures represent the machine terminals to be at a point $^1/_4$ of the distance from each end of the system. In practice, however, other points may be readily assumed to be machine terminals. Also, a number of machines may be grouped together to represent the "generator" of this simple system. In these figures the neutral of the generator has been taken as the zero point and all distances measured from that point to the neutral of the motor, and the complete distance being assumed to be one unit. Any measurement of distance will, therefore, be given as a fraction, *P*.

The figures previously discussed dealt only with internal generated voltages—quantities which are not ordinarily read by switchboard instruments. The zero line may be considered to be the neutral point of the entire system or it may be considered merely the reference point from which voltage is measured at any one location. It applies just as well to a delta voltage as to a star voltage measurement, but in these illustrations the star voltage is represented in its proper relation to the current.

In figure 3 is illustrated a simple system having the machines equally excited and carrying no load. The voltage will, therefore, be equal throughout the system and will everywhere be the same as the generated voltage. If one of these machines has no field, the conditions shown in figure 4 will exist. If all the different parts of the system have the same relative resistance and reactance, the voltage between wires will decrease uniformly along the line from the center of the generator to the center of the motor and will have the same phase relation throughout. The reason for showing the conditions in figure 4 becomes apparent in the next figure where, to the condition first shown are added the rotating vector conditions of the second machine. Here circles are drawn at 3 different points on the system for $^1/_4$, $^1/_2$, and $^3/_4$ of the distance

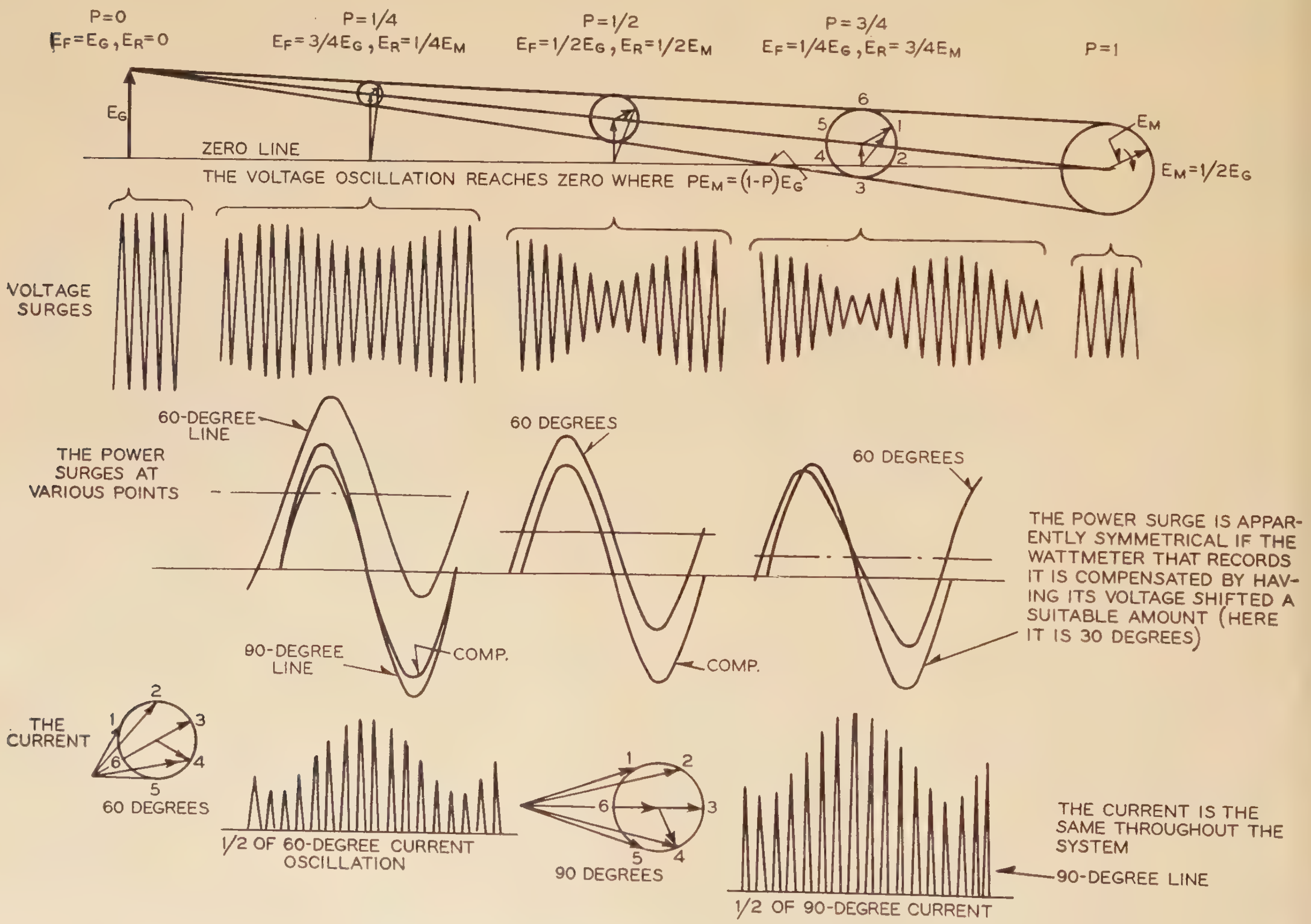

P=0
EF=EG, ER=0
P=1/4
EF=3/4EG, ER=1/4EM
P=1/2
EF=1/2EG, ER=1/2EM
P=3/4
EF=1/4EG, ER=3/4EM
P=1
EG
ZERO LINE
6
5
1
4
2
3
EM
EM=1/2EG
THE VOLTAGE OSCILLATION REACHES ZERO WHERE PEM=(1-P)EG
VOLTAGE SURGES
60-DEGREE LINE
THE POWER SURGES AT VARIOUS POINTS
60 DEGREES
60 DEGREES
THE POWER SURGE IS APPARENTLY SYMMETRICAL IF THE WATTMETER THAT RECORDS IT IS COMPENSATED BY HAVING ITS VOLTAGE SHIFTED A SUITABLE AMOUNT (HERE IT IS 30 DEGREES)
90-DEGREE LINE
COMP.
COMP.
THE CURRENT
1
2
3
4
5
6
60 DEGREES
1/2 OF 60-DEGREE CURRENT OSCILLATION
1
2
3
4
5
6
90 DEGREES
1/2 OF 90-DEGREE CURRENT
THE CURRENT IS THE SAME THROUGHOUT THE SYSTEM
90-DEGREE LINE

Figure 6. The motor voltage is $^1/_2$ the generator voltage

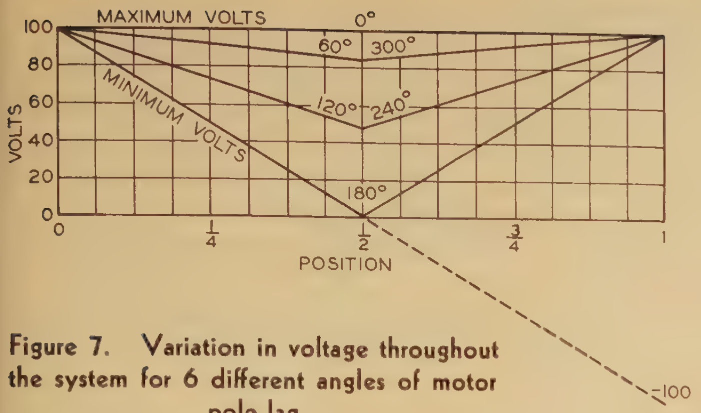


Figure 7. Variation in voltage throughout the system for 6 different angles of motor pole lag

between the generator neutral and the motor neutral.

Below each of these points is shown a cycle of the voltage oscillation at that point. It will be observed that the voltage oscillates to zero only at one point on the system which will be the center of the line if the 2 generated voltages are equal. If the voltages are unequal, as shown in figure 6, the point of zero voltage occurs in some other location on the system. Another way of showing this is by the curves in figures 7 and 8. These 2 figures will be of importance in studying the performance of line sectionalizing relays, particularly those of the distance-measuring type. Since minimum voltage and maximum current occur at the same time, it will be possible from these figures to determine what line relays are in danger of tripping during out-of-step conditions.

This system, with generator and motor voltages equal, is symmetrical and at first sight it seems strange that the vectors where $P = {}^1/_4$ appear to be so different from those where $P = {}^3/_4$. However, closer inspection will show that the resultant vectors are the same. It will be observed that although the swing of the vectors is different in the 2 positions, their absolute values are equal at any given time of reference. When they are plotted as scalar values they will be equal, as is shown in the voltage wave plotted below each point.

This is a good time to again emphasize that these are not vectors of instantaneous values. For example, in figure 5 the vector OY is the sum of the vector OX and XY and this sum never reaches zero. This is shown in the voltage waves below the diagrams. The following additional facts concerning the current and voltage surges may be summarized:

1. When 2 machines are out of step there is only one point on the system where the effective voltage between wires drops to zero.

2. The position of zero voltage depends upon the relative excitation of the 2 machines.

3. The current will not become zero unless the excitation of the 2 machines is equal.

4. The system can be assumed to be symmetrical even though the machines may have different reactance values. Under such conditions, the terminals of the 2 machines are assumed to be at different distances from their centers.

5. Similarly, in considering a large generator or a group of generators connected to a small motor, the center of the system may be within the motor windings.

6. In this latter case there is no point outside of the machines where the voltage between wires will drop to zero during out-of-step conditions.

Determining Power Surges

The most interesting part of this study is the analysis of the power flow. It has been generally recognized that the power oscillations are not the same throughout the system, but the way in which the oscillations vary at different points has been hard to understand.

The current is, of course, the same throughout the system, but the voltage is different at every point. As mentioned previously, the current vector consists of an unchanging quantity plus a rotating component which rotates with the slipping pole. The same thing is true of the voltage vectors. The flow of power between the centers of the 2 machines at any point is the product of the current and voltage vectors and the cosine of the angle between them. These vector diagrams for several points on the system are shown in figures 5 and 6. Below each of the vectors showing the voltage variations is plotted the envelope of the voltage pulsation at that point. Below this is plotted the average value of the power surge. This has been obtained by multiplying the current and voltage values by the cosine of the angle between them for various positions. Corresponding points on the current and the voltage reference circles have been marked 1, 2, 3, etc. The angles between corresponding voltage and current values are not shown, but they can easily be determined from the various figures by simple manipulations of a straight-edge and a triangle.

When plotting a power surge, a table should be prepared having the following headings:

ϕ	I	E	Angle Between E and I	Cosine Angle	Watts

This is about as easy a method as any. A trigonometric formula for the power surge at any point has been derived, but the final quantity that is obtained consists of the sum of a numerical term, a cosine term, and a sine term. The addition of these 3 quantities, if they are to be plotted, is usually more laborious than the method outlined above.

The formula mentioned is:

$$\text{Watts} = \frac{R}{Z^2}(E_G{}^2 - PE_G{}^2 - PE_M{}^2) + \frac{R}{Z^2}(2P - 1)E_G E_M \cos\phi + \frac{X}{Z^2} E_G E_M \sin\phi$$

where:

R = resistance, X = reactance, Z = impedance of the conductor from the neutral of one machine to the neutral of the other
E_G = internal voltage of the generator
E_M = internal voltage of the motor
ϕ = the angle of separation between the poles of the 2 machines
P = point where the watts are being measured

The meaning of the symbols is shown in figure 5. If the system is assumed to have no resistance, the first 2 terms vanish, leaving only the expression:

$$\text{Watts} = \frac{E_G E_M}{X} \sin\phi$$

This is the only condition where the flow of power is equal in each direction. Its value is also the same throughout the system because there is no resistance to consume power.

The value of the watts depends upon the product of the 2 voltages. If one of the voltages is decreased to $^1/_2$, the power interchange is decreased by the same amount. If one of the voltages is decreased to zero, the power interchange becomes zero.

As to the actual angle of a real system, there are probably none having a natural angle of more than 85 degrees. Many have an angle of around 80 degrees and more of 75 degrees. Systems of 60 degrees or even 45 degrees do exist. On such a system the power surges are not equal in the positive and negative direction, except at its center.

By reference to figures 5 and 6, it will be observed how this value varies at different points on the system under different conditions of excitation. The assumed angle in all these diagrams is 60 degrees.

Several different power curves are shown in figure 6. First, are the 3 normal curves for a 60-degree system having its motor excited to half voltage. Second, there is shown the symmetrical power wave which exists on a similar line having no resistance. The 2 sets of current vectors for these 2 different cases are shown on the diagram for comparison. Third, a set of compensated power curves is shown.

These compensated curves have particular application to the relay problem of protecting synchronous machinery. It has previously been shown that the voltage surges at a definite point cannot be predetermined if the excitation of the 2 machines varies in an unknown manner. The same is true of the current surges. But the power waves can be compensated so they are symmetrical. The reason for the symmetrical wave on the ideal system having no resistance is that the axes of the voltage diagram and of the current diagram are at right angles to each other. On a system where the current lags less than 90 degrees, the same effect can be obtained by compensating the wattmeter or the watt relay so that it has its zero torque at the natural angle of the system. On a 60-degree system this can be easily done by connecting the watt relay to utilize the star current and the delta voltage of the phase which is leading by 30 degrees. This differs from the usual arrangement of watt relays for line protection in that such relays are connected to the star current and the voltage that lags by 30 degrees.

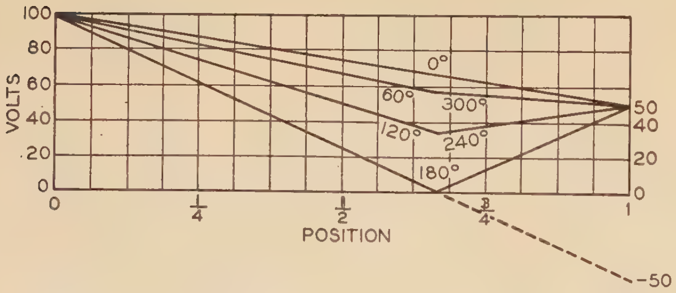


Figure 8. Variation of the voltage when the motor voltage is 50 per cent of the generator voltage

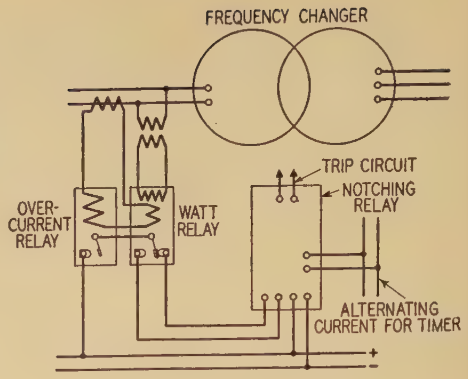


Figure 9. Protecting frequency changers from operating out of step

It is of interest to observe that the power wave has the same frequency as the voltage and current surges—not double frequency, as would be the case, if it were the product of 2 sine waves.

Constants Used in the Calculations

The resistance and reactance of the transmission lines can be obtained from standard transmission line tables. The per cent resistance of the windings of machines and transformers may be assumed to be one per cent at their rated kilovolt-amperes. Synchronous machines have several different reactance values. The one that should be used in these calculations is the one now known as the transient reactance (X_d'). The following table of typical 60-cycle values is copied from the "Relay Handbook."

Turbine generator (2 pole): 12–22 per cent
Turbine generator (4 pole): 20–29 per cent
Salient-pole machines: 21–50 per cent
Condensers: 30–60 per cent
Power transformers: up to 66 kv 5–7 per cent
88 to 110 kv 6–9 per cent
132 to 154 kv 8–10 per cent
187 to 220 kv 10–14 per cent

There are, of course, many factors which cannot be easily evaluated such as the effect of the load on the system and the proper method of grouping separated machines in order to simplify the setup. There is also an uncertain factor in the induction motor effect of the starting windings of the motors. Presumably, this will throw the power curve off the zero line.

Another variable is the effect of short circuits—the most common cause of out-of-step conditions. An unbalanced short circuit may cause machines to fall out of step before it is cleared. A 3-phase short circuit may, in effect, separate the machines during the time that it exists and, when the trouble is cleared by the proper breakers, the machines will be out of step. Sometimes they will pull back into step but often they will not.

Out-of-Step Relay Protection

A synchronous machine can run out of step indefinitely and damage has been done to several machines of various types from this cause. One result of out-of-step operation is overheating of the damper or starting windings. Another possible trouble with frequency changers and turbine generators is mechanical resonance of the rotor and the shaft, which form a torsion pendulum, with the out-of-step surges. Because of the rapidity with which dangerous resonant forces might conceivably be built up, some machines have been protected by out-of-step relays that will quickly disconnect a machine after it has slipped a definite number of poles, say 3 or 4 pairs.

The few installations of out-of-step protection with which the writer is familiar all use an out-of-step relay which actuates a notching relay. The notching relay in turn trips the breaker after the set number of notches has been registered.

Several forms of out-of-step relays have been used. On one system where it is desired to open sectionalizing breakers near the center of the system and at the lower capacity generating points, a low-voltage relay is used—a so-called "dip counter." This device can be applied when the out-of-step conditions, for which it must operate, are accompanied by dips in voltage below normal by a sufficient amount for operation of the actuating voltage relay once during each slip cycle.

Notching relays operated by current impulses are more common but it is probable that they will not fit all operating conditions. Such a current relay must be set high enough so that it will not operate if the machine is hunting—particularly after a short circuit has cleared. This high setting may be too high to allow operation under all values of field strength. Conditions may be such that the current relay will pick up and stay up because the current does not drop to a low enough value; or if the field is weak, the relay may not pick up at all.

An out-of-step relay that satisfies all of the conditions so far raised consists of a duodirectional watt relay and an overcurrent relay with their contacts in series. The watt relay can be compensated to have its zero-torque position agree with the angle of the line. This is done in the design of the relay itself when the angle to be compensated for is small. Such a relay will follow the power oscillations and make contact alternately in the positive and negative direction and step up the notching relay on each impulse.

The overcurrent relay should be set low, possibly below full load current. Its object is to insure that the watt relay will not operate when the machine is hunting. If the motor is lightly loaded the watt element may oscillate each side of zero but the current element contacts will be open. If, however, the motor is loaded so heavily that the current contacts are closed, the effect of hunting will be to cause the power to surge up and down without crossing over the zero line and becoming negative. A schematic diagram of the relay combination is shown in figure 9.

The notching relay may be a mechanical device or it may be constructed from a counting chain of auxiliary relays arranged so that each link will notch up in succession as successive impulses are given to it by the out-of-step relay. Any notching relay will be given a single energizing impulse whenever a short circuit occurs on the system. It is, therefore, necessary to reset the device after every short circuit on the system and it will also be convenient to reset it after every disturbance where it has stepped up a few notches but not enough to trip the breaker. This function may be performed automatically by means of a timing device which is set in motion by the first notch and will reset the relay, if the notching sequence is not completed within a specified time. In one commercial design of notching relay this timer can be adjusted for any value between zero and 10 seconds.

Line Sectionalizing Relays Under Out-of-Step Conditions

The analysis given in this paper will be particularly useful in the study of transmission line relays where it is desired to prevent them from operating when the system is out of step. The factors involved are numerous and special attention must be given to every different type of relay installation. It is possible to determine the performance of the directional elements of the relays at every point taking into account the phase connection of the voltage terminals of the relay. The performance of impedance and reactance relays can likewise be determined for each location. From such a study it should be possible to prevent undesirable performance during out-of-step operation or to arrange the relays so that the line can be sectionalized at any desired point when out-of-step conditions exist. Although the principles herein outlined have been presented in a simple manner, they are fundamental and should serve as a useful guide in the study of any relay problems where out-of-step conditions are encountered.

Use of Electricity to Treat Disease Fulfills Half-Century-Old Prophecy

A PROPHECY made over half a century ago, that electricity would be used in treating disease, has come true, and the scientist who made it is still alive to see his then rash statement justified.

The scientist is the 86-year-old Professor A. D'Arsonval, of Paris, whose galvanometer is familiar to every high school physics student. He recalled his early statement in a message to the first International Conference on Fever Therapy recently held in New York. Professor D'Arsonval is honorary president of the French committee of the conference.

"I am forgiven today," Professor D'Arsonval concludes his message, "for the phrase which I am proud of having written in 1882 and to which, at the time, I owed the animosity of doctors and pharmaceutical chemists.

" 'I am persuaded,' I said, 'that the therapeutic of the future will employ, as a curative means, the physical modificators, heat, light, electricity, and other agents still unknown . . . and that the most poisonous drugs of chemistry will have to give place to these imponderables that have the advantage of introducing no poison into the organism.' "

Alternator Short-Circuit Currents Under Unsymmetrical Terminal Conditions

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General Introduction

IN A PREVIOUS PAPER[1] the solution for the ideal alternator under symmetrical terminal conditions was developed. In this paper the application of the equations developed in this previous paper are used, together with symmetrical components of currents, to obtain the solution of currents in the armature and field circuits of an alternator under unsymmetrical fault conditions. These equations and solutions are applied to a 3-phase alternator having a line-to-ground and a line-to-line fault condition, under various conditions. Oscillograms and calculated graphs are compared to check the method used in this solution, and excellent results are obtained. Due to the inclusion of resistance simultaneously in the armature and field circuits, the frequency of the harmonics in the circuits are seen to be somewhat different than usually given under less approximate assumptions. Also, the effect of resistance is more closely determined by this method of solution.

Application of Symmetrical Components

The rigorous solution of the polyphase alternator assumes symmetrical terminal conditions of current. That is, the current in each phase was the same as that in every other phase, except for the difference in phase relationship.

This symmetrical terminal solution is extended to the solution of unsymmetrical fault conditions by assuming that the customary symmetrical components of positive-, negative-, and zero-sequence currents are simultaneously applied in such a fashion of phase and magnitude as will give the terminal conditions as actually exist. It is possible to so arrange these sets of sequence currents to duplicate any terminal condition chosen. Thus in a line-to-line fault, these currents (including the so-called "steady-state" and "transient" components of the solution) when added together in the open phase must give no current in that phase. Likewise, in a line-to-ground fault, the 2 open phases will have no current when the sequence currents obtained for these phases are added. The first case will require only positive- and negative-sequence components of current, while the latter will require positive-, negative-, and zero-sequence components. These statements refer not only to the fundamental component of current, but to harmonic components as well.

Using these component symmetrical currents, the equivalent impedance of the alternator will need to be known for each. In general, in case harmonic armature and field currents are set up, the impedance to the fundamental and all related harmonics must be known, when flowing simultaneously.

Limiting the discussion to a line-to-line and line-to-ground fault, it would in general be expected that the impedance to the negative-sequence set of symmetrical currents would be different for the 2 cases. In the line-to-line fault the positive and negative fundamental components of current must cancel each other in the open phase; however, the negative-phase-sequence currents give rise to third harmonic currents, which in turn will require positive- and negative-sequence components that cancel each other in the open phase and so on. Since positive- and negative-sequence components of currents are involved, the impedance to the fundamental negative-sequence current will be dependent on these only. In the case of a line-to-ground fault, harmonics of positive, negative, and zero-sequence are set up by the fundamental negative-sequence component current. Because of this difference in the harmonics, depending upon the type of fault, different harmonics encountered require a different value of negative-sequence impedance. For the cases calculated in this paper, these impedances are discussed at some length in appendix *A*.

Review of 3-Phase Short-Circuit Solution

In a previous paper by the authors[1] there were developed equations for finding the armature and field currents upon the application of a 3-phase short circuit to an alternator. There were also developed a number of equations for a 3-phase machine that could be applied for various conditions. These equations are important and will be repeated here although no derivation will be given.

$$e_d = -p\psi_d - \psi_q\,(p\theta) - i_dR \qquad (1)$$

$$e_q = -p\psi_q + \psi_d\,(p\theta) - i_qR \qquad (2)$$

$$E_{fd} = p\psi_{fd} + I_{fd}R_{fd} \qquad (3)$$

$$\psi_{fd} = X_{ffd}I_{fd} + X_{fad}i_d \qquad (4)$$

$$\psi_d = X_{afd}I_{fd} + x_di_d \qquad (5)$$

$$\psi_q = x_qi_q \qquad (6)$$

These equations have been set up assuming that there is only the main field winding in the direct-axis rotor circuit and no windings on the quadrature-axis rotor circuit.

In order to solve for a 3-phase short circuit the 6 equations above are combined into the following 3 equations.

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted June 25, 1937; released for publication August 7, 1937.

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[1] For all numbered references, see list at end of paper.

$$e_d = -(R + px_d)i_d - x_q i_q - pX_{afd}I_{fd} \tag{7}$$

$$e_q = x_d i_d - (R + px_q)i_q + X_{afd}I_{fd} \tag{8}$$

$$E_{fd} = pX_{fad}i_d + (R_{fd} + pX_{ffd})I_{fd} \tag{9}$$

These equations solved simultaneously by means of determinants give the following equations for the unknown currents.

$$\left.\begin{aligned} i_d &= [e_q(x_qR_{fd} + px_qX_{ffd}) - e_d(p^2x_qX_{ffd} + px_qR_{fd} + \\ &\quad pRx_{ffd} + RR_{fd}) - E_{fd}X_{afd}(p^2x_q + pR + x_q)]/D(p) \\ i_q &= [e_d(pX_{afd}X_{fad} - px_dX_{ffd} - x_dR_{fd}) + E_{fd}(RX_{afd}) - \\ &\quad e_q(p^2x_dX_{ffd} - p^2X_{afd}X_{fad} + pRX_{ffd} + pR_{fd}x_d + \\ &\quad RR_{fd})]/D(p) \\ I_{fd} &= [E_{fd}(p^2x_dx_q + pRx_q + pRx_d + R^2 + x_dx_q) - \\ &\quad e_q(pX_{fad}x_q) + e_d(p^2x_qX_{fad} + pRX_{fad})]/D(p) \end{aligned}\right\} \tag{10}$$

where

$$\begin{aligned} D(p) = {} & p^3(x_dx_qX_{ffd} - X_{afd}X_{fad}x_q) + p^2(x_qx_dR_{fd} + Rx_dX_{ffd} + \\ & Rx_qX_{ffd} - X_{afd}X_{fad}R) + p(RR_{fd}x_d + RR_{fd}x_q + \\ & R^2X_{ffd} + x_dx_qX_{ffd} - X_{afd}X_{fad}x_q) + (R^2R_{fd} + x_dx_qR_{fd}) \end{aligned}$$

The currents in the various phases are found from the following equations.

$$i_a = i_d \cos\theta + i_q \sin\theta \tag{11}$$

$$i_b = i_d \cos(\theta - 120) + i_q \sin(\theta - 120) \tag{12}$$

$$i_c = i_d \cos(\theta + 120) + i_q \sin(\theta + 120) \tag{13}$$

where

$$\theta = t + \theta_0 \tag{14}$$

Also

$$e_d = \frac{2}{3}[e_a \cos\theta + e_b \cos(\theta - 120) + e_c \cos(\theta + 120)] \tag{15}$$

$$e_q = \frac{2}{3}[e_a \sin\theta + e_b \sin(\theta - 120) + e_c \sin(\theta + 120)] \tag{16}$$

and

$$x_d' = x_d - \frac{X_{afd}X_{fad}}{X_{ffd}} \tag{17}$$

Theory of Single-Phase Solution

In order to satisfy terminal conditions in a line-to-ground fault, it is necessary to have positive-, negative-, and zero-sequence currents equal to each other and in-phase in phase a. The value of positive-sequence current is found by applying the voltage to a circuit consisting of positive-, negative-, and zero-sequence reactances in series. The sum of these reactances in the direct and quadrature axes will be x_{dT} and x_{qT} referred to as totalized reactances. The value of x_2 to be used is discussed in appendix A. These totalized values of direct- and quadrature-axis reactances are now used in equations 10 for the solution of a 3-phase short circuit and solutions will be obtained for i_d, i_q, and I_{fd}.

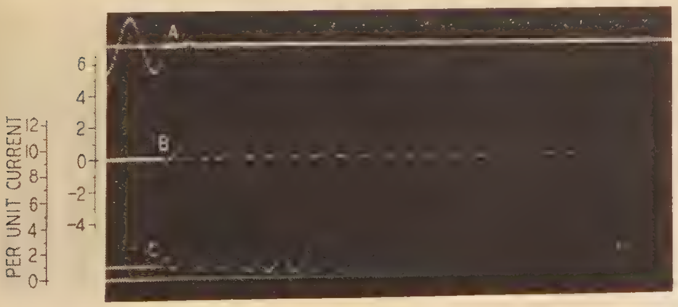

Figure 1. Oscillogram of line-to-ground short circuit

A—Phase a voltage; *B*—Armature current; *C*—Field current

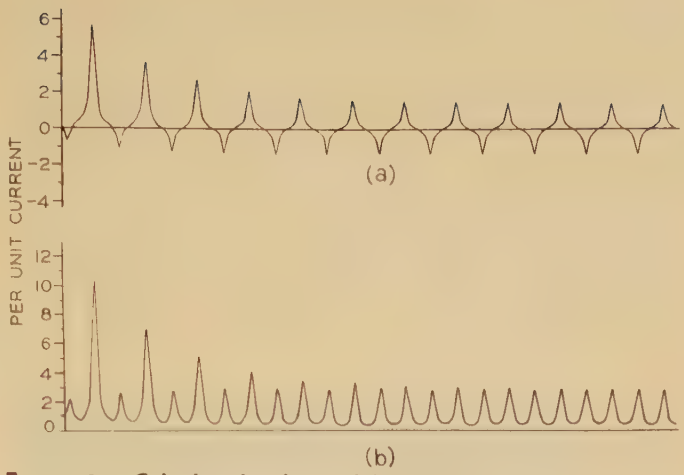

Figure 2. Calculated values of line-to-ground short circuit

(*a*) Armature current

$$i_a = \frac{0.396 \sin(\omega t + 242°38') + 0.733\epsilon^{-0.09\omega t}\sin(\omega t + 242°38')}{1.224 - 0.946\cos(2\omega t + 288°)} + \frac{0.061\epsilon^{-0.103\omega t}\sin(1.991\omega t + 132°31')}{1.224 - 0.946\cos(2\omega t + 288°)} + \frac{1.109\epsilon^{-0.103\omega t}\sin(0.009\omega t + 59°40')}{1.224 - 0.946\cos(2\omega t + 288°)}$$

(*b*) Field current

$$\begin{aligned} I_{fd} = {} & 1 + 1.84\epsilon^{-0.09\omega t} + 1.84\epsilon^{-0.103\omega t}\sin(0.991\omega t + 269°15') - \\ & \frac{0.946\sin(2\omega t + 201°6') + 0.447}{1.224 - 0.946\cos(2\omega t + 288°)} + \\ & \frac{[1.757\sin(2\omega t + 201°6') + 0.830]\epsilon^{-0.09\omega t}}{1.224 - 0.946\cos(2\omega t + 288°)} - \\ & \frac{[(0.875\sin(2.991\omega t + 18°47')]\epsilon^{-0.108\omega t}}{1.224 - 0.946\cos(2\omega t + 288°)} + \\ & \frac{[1.82\sin(1.009\omega t + 22°11')]\epsilon^{-0.103\omega t}}{1.224 - 0.946\cos(2\omega t + 288°)} + \\ & \frac{[1.271\sin(0.991\omega t + 87°26')]\epsilon^{-0.103\omega t}}{1.224 - 0.946\cos(2\omega t + 288°)} \end{aligned}$$

The armature currents that are found by this solution are only the fundamental-frequency positive-phase-sequence currents flowing in the armature, so that the value of i_a obtained from the above values of i_d and i_q is ${}_1i_{a1}$. For a line-to-ground short circuit the total short-circuit current in phase a is equal to 3 times the sequence current due to the fact that positive-, negative-, and zero-sequence currents are equal so that the true value of ${}_1i_a$ is equal to 3 times ${}_1i_{a1}$.

The fact that there is negative-sequence current flowing in the armature produces currents of frequency 2 higher than the fundamental solution, and gives rise to several series of terms of higher frequencies. These series will be referred to as harmonic series throughout this paper although it will be seen that the series are not made up of harmonics but of a series of terms each of frequency 2 higher than the term that preceded it. In order to obtain the solution for the actual armature currents, the harmonics that go with ${}_1i_a$ must be found and added to it. The actual process of obtaining the total short-circuit current, including these harmonics, is given in appendix *B*.

The solution of I_{fd} as found from equation 10 is, in a manner similar to the solution for armature current, only a part of the total current. The harmonics in the field current arise from the harmonic currents flowing in the armature. Therefore the harmonics in the field are calculated from the total i_d flowing in the armature by solving equation 9 for I_{fd}.

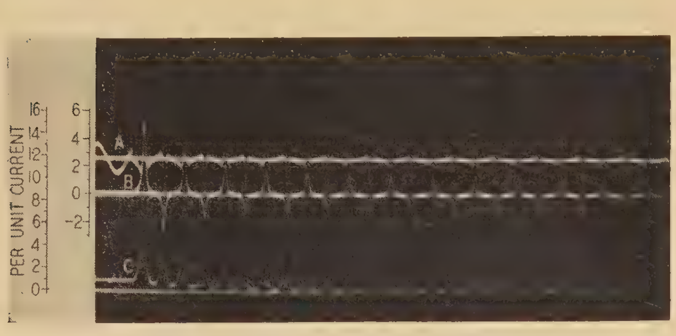

Figure 3. Oscillogram of line-to-line short circuit

A—Phase *a* voltage; *B*—Phase *b* current; *C*—Field current

Letting $E_{fd} = 0$

$$I_{fd} = \frac{pX_{fad}i_d}{R_{fd} + pX_{ffd}}$$

The series are geometric in form so that once 2 terms have been found the rest of the series is determined.

The same process is used to obtain the solution for a line-to-line short circuit. In this case there are no zero-sequence currents and the equation for x_2 will be different than that used in the line-to-ground solution.

Conclusions

By the application of symmetrical components of currents to polyphase-alternator short-circuit solutions it has been possible to include the resistance in both the armature and field circuits in a much more satisfactory manner than is usually found in unsymmetrical alternator short-circuit solutions. In order to shorten the numerical calculations, some approximations have been made in the inclusion of the resistances of the machine circuits, but these approximations have only a negligible effect. Moreover, these solutions are similar to the general 2-reaction theory as developed for symmetrical short-circuit solutions, and give solutions which agree experimentally. The oscillograms included in the paper were taken on a small laboratory machine; even closer results could be obtained on larger commercial machines, in which the constants were known.

Appendix A

NEGATIVE-SEQUENCE REACTANCE

By applying the constant-flux-linkage theorem to a line-to-ground fault, Doherty[2] has shown that the initial value of the fundamental component of current is

$$i = \frac{2e_0}{x_D' + \sqrt{x_D'x_Q'}} \qquad \text{(1a)}$$

By the principle of symmetrical components, this is also equal to

$$i = \frac{3e_0}{x_d' + x_2 + x_0} \qquad \text{(2a)}$$

Therefore

$$\frac{3}{x_d' + x_2 + x_0} = \frac{2}{x_D' + \sqrt{x_D'x_Q'}}$$

Park[3] has shown that the following relations exist between the single-phase static constants and the 3-phase constants.

$$x_D' = \frac{x_0 + 2x_d'}{3}$$

$$x_Q' = \frac{x_0 + 2x_q'}{3}$$

Substituting and solving for x_2

$$x_2 = \frac{\sqrt{(x_0 + 2x_d')(x_0 + 2x_q')}}{2} - \frac{x_0}{2} \qquad \text{(3a)}$$

Park has shown that for a line-to-line fault the relation between single-phase and 3-phase constants differ from the line-to-ground relations.

$$x_D' = 2x_d'$$

$$x_Q' = 2x_q'$$

Thus the initial value of the fundamental current during a line-to-line fault as given by Doherty becomes

$$\frac{2\sqrt{3}e_0}{x_D' + \sqrt{x_D'x_Q'}} = \frac{\sqrt{3}e_0}{x_d' + \sqrt{x_d'x_q'}}$$

But by symmetrical components this current is also

$$\frac{\sqrt{3}e_0}{x_d' + x_2}$$

Now equation the 2 expressions and solving for x_2

$$x_2 = \sqrt{x_d'x_q'} \qquad \text{(4a)}$$

Thus it is seen that x_2 varies with the kind of fault.

For a line-to-ground fault the external reactances of the sequence network are x_2 and x_0 in series.
Therefore

$$x_{dT} = x_d + x_2 + x_0$$
$$x_{qT} = x_q + x_2 + x_0$$

Similarly

$$x_{dT}' = x_d' + x_2 + x_0$$
$$x_{qT}' = x_q' + x_2 + x_0$$

For a line-to-line fault, the external reactance is only the negative-sequence reactance and the totalized impedances are

$$x_{dT} = x_d + x_2$$
$$x_{qT} = x_q + x_2$$
$$x_{dT}' = x_d' + x_2$$
$$x_{qT}' = x_q' + x_2$$

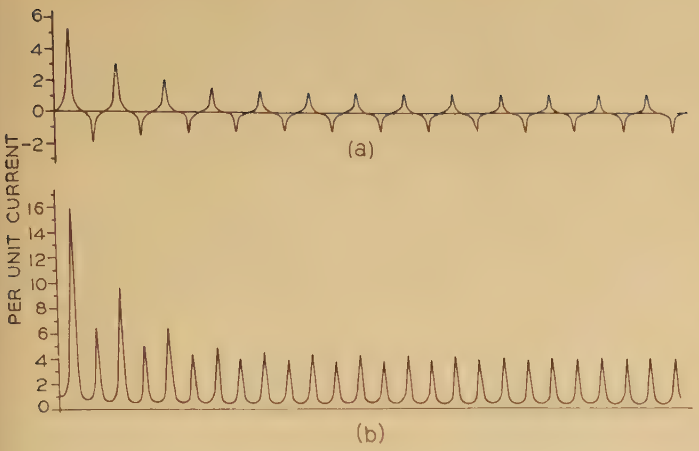

Figure 4. Calculated values of line-to-line short circuit

(*a*) Armature current

$$i_b = \frac{0.208 \sin(\omega t + 345°1') + 0.599\epsilon^{-0.123\omega t}\sin(\omega t + 345°1')}{1.342 - 1.170\cos(2\omega t + 132°)} + \frac{0.064\epsilon^{-0.101\omega t}\sin(1.991\omega t + 248°22')}{1.342 - 1.170\cos(2\omega t + 132°)} + \frac{0.798\epsilon^{-0.101\omega t}\sin(0.009\omega t + 161°1')}{1.342 - 1.170\cos(2\omega t + 132°)}$$

(*b*) Field current

$$I_{fd} = 1.0 + 2.88\epsilon^{-0.123\omega t} + 2.884\epsilon^{-0.101\omega t}\sin(0.991\omega t + 271°26') - \frac{1.17\sin(2\omega t + 44°23') + 0.681}{1.342 - 1.170\cos(2\omega t + 132°)} + \frac{[3.37\sin(2\omega t + 44°23') + 1.96]\epsilon^{-0.123\omega t}}{1.342 - 1.170\cos(2\omega t + 132°)} - \frac{[1.68\sin(2.991\omega t + 224°35')]\epsilon^{-0.101\omega t}}{1.342 - 1.170\cos(2\omega t + 132°)} + \frac{[2.87\sin(1.009\omega t + 224°26')]\epsilon^{-0.101\omega t}}{1.342 - 1.170\cos(2\omega t + 132°)} + \frac{[2.657\sin(0.991\omega t + 89°25')]\epsilon^{-0.101\omega t}}{1.342 - 1.170\cos(2\omega t + 132°)}$$

If any impedance external to the machine is present, it must be added to x_d, x_2, and x_0, etc. Thus for an external impedance of x_{ex} in a line-to-ground fault

$$x_{dT} = x_d + x_2 + x_0 + 3x_{ex} \tag{5a}$$

Similar equations must be written for x_{qT}, and for the transient reactances x_{dT}' and x_{qT}'.

An external impedance in a line-to-line fault is taken into account similarly except that x_0 is not present; therefore only $2x_{ex}$ must be added.

$$x_{dT} = x_d + x_2 + 2x_{ex}, \text{ etc.} \tag{6a}$$

In order to see the formation of higher frequency currents, let a negative-sequence voltage of frequency n be impressed.

$$e_a = \sin nt$$
$$e_b = \sin(nt - 120)$$
$$e_c = \sin(nt + 120)$$

And then from equations 15 and 16

$$e_d = \sin(n + 1)t$$
$$e_q = -\cos(n + 1)t$$

From equations 1 and 2

$$e_d = -p\psi_d - \psi_q(p\theta) - i_dR$$
$$e_q = -p\psi_q + \psi_d(p\theta) - i_qR$$

But using the totalized reactances

$$\psi_d = x_{dT}'i_d$$
$$\psi_q = x_{qT}'i_q$$

With $p\theta = 1$ and neglecting R

$$e_d = \sin(n + 1)t = -p\,x_{dT}'i_d - x_{qT}'i_q$$
$$eq = -\cos(n + 1)t = -p\,x_{qT}'i_q + x_{dT}'i_d$$

Solving for i_d and i_q

$$i_d = \frac{\cos(n + 1)t}{n\,x_{dT}'}$$

$$i_q = \frac{\sin(n + 1)t}{n\,x_{qT}'}$$

Then from equation 11 the value of i_a becomes

$$i_a = \frac{1}{2n}\left(\frac{1}{x_{dT}'} + \frac{1}{x_{qT}'}\right)\cos nt + \frac{1}{2n}\left(\frac{1}{x_{dT}'} - \frac{1}{x_{qT}'}\right)\cos(n + 2)t \tag{7a}$$

From equation 7*a* the formation of higher frequencies can readily be seen. A negative-sequence current of frequency n will produce a positive-sequence current of frequency $(n + 2)$. That this is a positive-sequence current can readily be checked by finding the currents i_b and i_c similar to equation 7*a*. The important part of this equation is the relation of the magnitude of the 2 currents. This ratio is

$$\frac{\left(\frac{1}{x_{dT}'} - \frac{1}{x_{qT}'}\right)}{\left(\frac{1}{x_{dT}'} + \frac{1}{x_{qT}'}\right)} = \frac{x_{qT}' - x_{dT}'}{x_{qT}' + x_{dT}'} \tag{8a}$$

Therefore if a negative-sequence current of frequency n is flowing there will also be flowing a positive-sequence current of frequency $(n + 2)$ whose amplitude bears the ratio to the first current as given by equation 8*a*.

Appendix B

ARMATURE CURRENT

From the theory of symmetrical components, the current that will be found by dividing the voltage by the network impedance for a line-to-ground fault is only the positive-sequence current.

$$i_{a1} = \frac{E}{x_1 + x_2 + x_0}$$

However there is also flowing a negative- and zero-sequence current equal to this value of i_{a1}. It is a known fact that harmonics exist

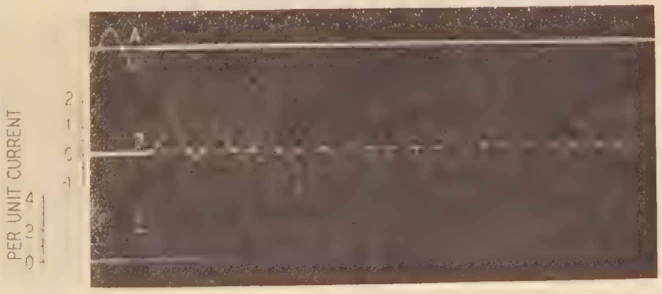

Figure 5. Oscillogram of line-to-ground short circuit with external reactance

A—Phase a voltage; *B*—Armature current; *C*—Field current

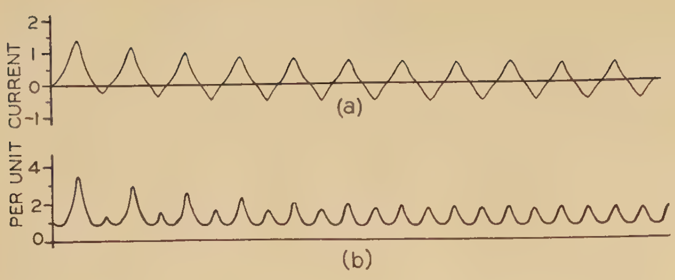

Figure 6. Calculated values of line-to-ground short circuit with external reactance

(*a*) Armature current

$$i_a = \frac{0.333 \sin(\omega t + 280°18') + 0.201\epsilon^{-0.051\omega t}\sin(\omega t + 280°18')}{1.053 - 0.462 \cos(2\omega t + 10°)} +$$

$$\frac{0.022\epsilon^{-0.075\omega t}\sin(1.999\omega t + 180°)}{1.053 - 0.462\cos(2\omega t + 10°)} +$$

$$\frac{0.525\epsilon^{-0.075\omega t}\sin(0.001\omega t + 98°)}{1.053 - 0.462\cos(2\omega t + 10°)}$$

(*b*) Field current

$$I_{fd} = 1.0 + 0.60\epsilon^{-0.051\omega t} + 0.60\epsilon^{-0.075\omega t}\sin(0.999\omega t + 268°37') -$$

$$\frac{0.46\sin(2\omega t + 283°19') + 0.106}{1.053 - 0.462\cos(2\omega t + 10°)} -$$

$$\frac{[0.277\sin(2\omega t + 283°19') + 0.064]\epsilon^{-0.051\omega t}}{1.053 - 0.462\cos(2\omega t + 10°)} -$$

$$\frac{[0.137\sin(2.999\omega t + 107°5')]\epsilon^{-0.075\omega t}}{1.053 - 0.462\cos(2\omega t + 10°)} -$$

$$\frac{[0.60\sin(1.001\omega t + 102°51')]\epsilon^{-0.075\omega t}}{1.053 - 0.462\cos(2\omega t + 10°)} +$$

$$\frac{[0.170\sin(0.999\omega t + 89°24')]\epsilon^{-0.075\omega t}}{1.053 - 0.462\cos(2\omega t + 10°)}$$

in the armature so the current as found above shall be referred to as fundamental positive-sequence current in phase *a*, or, ${}_1i_{a1}$.

$${}_1i_{a1} = A\sin(\omega t + \theta_0 + \alpha) = A\sin(\theta + \alpha)$$

where θ_0 is the angle between phase *a* and the direct axis at the instant of short circuit and α is the angle of lag of the armature circuit. This angle α is only slightly less than -90 degrees.

It was shown in appendix *A*, equation 8*a*, that if a negative-sequence current is flowing in the armature, there is set up a positive-sequence current of frequency 2 units higher and bearing a ratio to the original current of $\frac{x_{qT}' - x_{dT}'}{x_{qT}' + x_{dT}'}$. This ratio will be called *b* for convenience.

Now

$${}_1i_{a1} = A\sin(\theta + \alpha)$$
$${}_1i_{a2} = A\sin(\theta + \alpha)$$
$${}_1i_{a0} = A\sin(\theta + \alpha)$$

and

$${}_1i_a = 3A\sin(\theta + \alpha) \qquad \textbf{(1b)}$$

but ${}_1i_{a2}$ sets up a positive-sequence third harmonic current, ${}_3i_{a1}$, such that

$${}_3i_{a1} = bx\,{}_1i_{a2} = bA\sin(3\theta + \alpha)$$

and since

$${}_3i_{a1} = {}_3i_{a2} = {}_3i_{a0}$$
$${}_3i_a = 3bA\sin(3\theta + \alpha)$$

Now if

$${}_3i_{a2} = bA\sin(3\theta + \alpha)$$
$${}_5i_{a1} = b^2A\sin(5\theta + \alpha)$$

In similar manner there must be ${}_5i_{a0}$ and ${}_5i_{a0}$ and thus

$${}_5i_a = 3b^2A\sin(5\theta + \alpha)$$

or

$$i_a = 3A[\sin(\theta + \alpha) + b\sin(3\theta + \alpha) + b^2\sin(5\theta + \alpha) + \text{etc.}\ldots] \qquad \textbf{(2b)}$$

FIELD CURRENT

From equation 9

$$I_{fd} = \frac{E_{fd} - pX_{fad}i_d}{R_{fd} + pX_{ffd}}$$

E_{fd} has the same value before and after the instant of short circuit so that in calculating any additional field current E_{fd} is neglected.

$$I_{fd} = -\frac{pX_{fad}i_d}{R_{fd} + pX_{ffd}}$$

Neglecting R_{fd}

$$I_{fd} = -\frac{X_{fad}}{X_{ffd}}i_d \qquad \textbf{(3b)}$$

Therefore, in order to find the series of terms in I_{fd}, the series of terms in i_d must be found.

$$i_d = \frac{2}{3}[i_a\cos\theta + i_b\cos(\theta - 120) + i_c\cos(\theta + 120)]$$

$$i_b = i_c = 0$$

therefore

$$i_d = \frac{2}{3}i_a\cos\theta \qquad \textbf{(4b)}$$

Putting in the value of i_a term by term as found above gives for the first term

$${}_1i_d = \frac{2}{3} \times 3A\sin(\theta + \alpha)\cos\theta$$
$$= A\sin(2\theta + \alpha) + A\sin\alpha$$

In similar manner

$${}_3i_d = bA\sin(4\theta + \alpha) + bA\sin(2\theta + \alpha)$$

and

$${}_5i_d = b^2A\sin(6\theta + \alpha) + b^2A\sin(4\theta + \alpha)$$

or

$$i_d = A\sin\alpha + (1 + b)A[\sin(2\theta + \alpha) + b\sin(4\theta + \alpha) + b^2\sin(6\theta + \alpha) + \ldots] \qquad \textbf{(5b)}$$

To find the total armature current the harmonics due to negative-sequence current were found and added to the solution of ${}_1i_a$ as found from equation 1*b*. Therefore only the harmonics in the field current that come from the negative-sequence fundamental current must be added to the solution of I_{fd} from equation 10.

$${}_1i_{a1} = A\sin(\theta + \alpha)$$

$${}_1i_{d1} = \frac{2}{3}[{}_1i_{a1}\cos\theta + {}_1i_{b1}\cos(\theta - 120) + {}_1i_{c1}\cos(\theta + 120)]$$
$$= A\sin\alpha$$

$${}_1i_{d2} = \frac{2}{3}[{}_1i_{a2}\cos\theta + {}_1i_{b2}\cos(\theta - 120) + {}_1i_{c2}\cos(\theta + 120)]$$
$$= A\sin(2\theta + \alpha)$$

Thus it is seen that in the equation for i_d the first term $A \sin \alpha$ comes from the fundamental positive-sequence current and is not part of the additional harmonics. Therefore in order to get I_{fd} only the terms in the bracket are applied to equation 3*b*. The additional terms of I_{fd} are then

$$I_{fd} = -\frac{X_{fad}}{X_{ffd}}(1+b)A\,[\sin(2\theta+\alpha)+b\sin(4\theta+\alpha)+ b^2\sin(6\theta+\alpha)+\ldots] \qquad (6b)$$

To obtain the total solution of I_{fd}, equation 6*b* must be added to the solution of I_{fd} from equation 10.

HARMONIC SERIES

It is very inconvenient to plot the series term by term. For that reason the development of an expression for the sum of each series is now given.

The series that occur in the armature and field currents are both of the following general form where X equals the sum.

$$X = \sin(n\theta+\alpha) + b\sin[(n+2)\theta+\alpha] + b^2\sin[(n+4)\theta+\alpha] + b^3\sin[(n+6)\theta+\alpha] + \ldots$$

Let $b = a^2$ and multiply both sides by a^n.

$$a^nX = a^n\sin(n\theta+\alpha) + a^{n+2}\sin[(n+2)\theta+\alpha] + a^{n+4}\sin[(n+4)\theta+\alpha] + \ldots$$

now

$$\sin(n\theta+\alpha) = \frac{\epsilon^{jn\theta}\epsilon^{j\alpha} - \epsilon^{-jn\theta}\epsilon^{-j\alpha}}{2j}$$

Writing the series with a summation sign

$$a^nx = \frac{1}{2j}\sum_{k=0}^{k=n}\left(a^{2k+n}\,\epsilon^{j(2k+n)\theta}\epsilon^{j\alpha} - a^{2k+n}\epsilon^{-j(2k+n)\theta}\epsilon^{-j\alpha}\right)$$

but

$$\sum_{k=0}^{k=n} a^{(2k+n)} = \frac{a^n}{1-a^2}$$

$$a^nx = \frac{1}{2j}\left[\frac{\epsilon^{j\alpha}a^n\epsilon^{jn\theta}}{1-a^2\epsilon^{j2\theta}} - \frac{\epsilon^{-j\alpha}a^n\epsilon^{-jn\theta}}{1-a^2\epsilon^{-j2}}\right]$$

$$= \frac{1}{2j}\left[\frac{\epsilon^{j\alpha}a^n\epsilon^{jn\theta} - a^{n+2}\epsilon^{j\alpha}\epsilon^{j(n-2)\theta} - \epsilon^{-j\alpha}a^n\epsilon^{-jn\theta} + a^{n+2}\epsilon^{-j\alpha}\epsilon^{j(n-2)\theta}}{1-a^2(\epsilon^{j2\theta}+\epsilon^{-j2\theta})+a^4}\right]$$

$$= \frac{1}{2j}\left[\frac{a^n(\epsilon^{j\alpha}\epsilon^{jn\theta} - \epsilon^{j\alpha}\epsilon^{jn\theta}) - a^{n+2}(\epsilon^{j\alpha}\epsilon^{j(n-2)\theta} - \epsilon^{-j\alpha}\epsilon^{-j(n-2)\theta}}{1-a^2(\epsilon^{j2\theta}+\epsilon^{-j2\theta})+a^4}\right]$$

$$a^nX = \frac{a^n\sin(n\theta+\alpha) - a^{n+2}\sin[(n-2)\theta+\alpha]}{1-2a^2\cos 2\theta + a^4}$$

$$X = \frac{\sin(n\theta+\alpha) - a^2\sin[(n-2)\theta+\alpha]}{1+a^4-2a^2\cos 2\theta}$$

but $a^2 = b$, therefore

$$X = \frac{\sin(n\theta+\alpha) - b\sin[(n-2)\theta+\alpha]}{1+b^2-2b\cos 2\theta}$$

where $\sin(n\theta+\alpha)$ is the first term of the series. Remembering that $\theta = \omega t + \theta_0$

$$\text{Sum} = \frac{\sin[n(\omega t+\theta_0)+\alpha] - b\sin[(n-2)(\omega t+\theta_0)+\alpha]}{1+b^2-2b\cos 2(\omega t+\theta_0)} \qquad (7b)$$

Appendix C

LINE-TO-GROUND SHORT CIRCUIT

Appendices *C*, *D*, and *E* illustrate the method of calculating various types of faults on a small laboratory machine, the constants of which are given below.

$$\begin{array}{lll} R_{fd} = 1.0 & x_d = x_q = 2.80 & \text{norm. } e_a = 63.5\sqrt{2} \\ X_{afd} = 1.0 & X_{fad} = 81.7 & i_a = 10\sqrt{2} \\ R = 0.073 & X_{ffd} = 31.5 & E_{fd} = 1.68 \\ & x_0 = 0.34 & I_{fd} = 13.95 \end{array}$$

$$x_d' = x_d - \frac{X_{afd}X_{fad}}{X_{ffd}} \qquad (17)$$

$$= 2.8 - 2.59 = 0.21$$

$$x_2 = \frac{\sqrt{2x_d' + x_0)(2x_q' + x_0)}}{2} - \frac{x_0}{2} \qquad (3a)$$

$$= \frac{1}{2}\sqrt{(0.42+0.34)(5.6+0.34)} - 0.17 = 0.89$$

The totalized reactances are then

$$x_{qT}' = 2.80 + 0.34 + 0.89 = 4.03$$

$$x_{dT}' = 0.21 + 0.34 + 0.89 = 1.44$$

$$b = \frac{4.03 - 1.44}{4.03 + 1.44} = \frac{2.59}{5.47} = 0.473$$

Assuming that the 3 sequence resistances are equal

$$R = R_1 + R_2 + R_0 = 3 \times 0.073 = 0.22$$

Now, using $x_{dT} = 4.03$ instead of $x_d = 2.80$ and $R = 0.22$ in the equations for a 3-phase short circuit,

$$i_{d1} = -0.248 - 0.459\epsilon^{-0.09\omega t} + 0.705\epsilon^{-0.103\omega t}\cos(0.991\omega t - 2°34')$$

$$i_{q1} = 0.0135 + 0.0248\epsilon^{-0.09\omega t} + 0.250\epsilon^{-0.103\omega t}\cos(0.991\omega t - 98°46')$$

$$I_{fd} = 1.0 + 1.84\,\epsilon^{-0.09\omega t} + 184\epsilon^{-0.103\omega t}\sin(0.991\omega t + 269°\ 15')$$

From the oscillogram $\theta_0 = 324°$

$$i_{a1} = i_{d1}\cos(\omega t+\theta_0) + i_{q1}\sin(\omega t+\theta_0)$$

and the fundamental value of i_a becomes

$${}_1i_a = 3\,i_{a1}$$

$${}_1i_a = 0.745\sin(\omega t + 237°6') + 1.38\,\epsilon^{-0.09\omega t}\sin(\omega t + 237°6') + 0.687\epsilon^{-0.103\omega t}\sin(1.991\,\omega t + 54°47') + 1.43\epsilon^{-0.103\omega t}\sin(0.009\omega t + 58°11')$$

Each of these 4 terms is followed by a series of harmonics but the term $(\omega t + \theta_0)$ must be factored out of $(\omega t + 237°6')$, etc. Thus for the first term of ${}_1i_a$

$$0.745\sin(\omega t + 237°6') = 0.745\sin[(\omega t + 324°) - 86°54']$$

The series of harmonics following the first term is

$$0.745\,(\sin[(\omega t+324°) - 86°54'] + b\sin[3(\omega t+324°) - 86°54'] + b^2\sin[5(\omega t+324°) - 86°54'] + \text{etc.})$$

The first term is in the form $\sin[n(\omega t+\theta_0)+\alpha]$ and the equation developed in appendix *B* can be used to get the sum.

$$\text{Sum} = \frac{\sin[n(\omega t+\theta_0)+\alpha] - b\sin[(n-2)(\omega t+\theta_0)+\alpha]}{1+b^2-2b\cos 2(\omega t+\theta_0)} \qquad (7b)$$

For the series following the first term of ${}_1i_a$

$b = 0.473 \qquad n = 1 \qquad (\omega t + \theta_0) = (\omega t + 324°) = \theta$

$\alpha = -86°54'$

$$\text{sum} = 0.745\,\frac{[\sin(\theta - 86°54') - 0.473\sin(-\theta - 86°54')]}{1.224 - 0.946\cos(2\omega t + 288°)}$$

$$= 0.745\,\frac{[0.532\sin(\theta - 81°22')]}{1.224 - 0.946\cos(2\omega t + 288°)} = \frac{0.396\sin(\omega t + 242°38')}{1.224 - 0.946\cos(2\omega t + 288°)}$$

In a similar manner the sum of the series following the second term is

$$= 1.38\epsilon^{-0.09\omega t}\,\frac{[0.532\sin(\theta-81°22')]}{1.224-0.946\cos(2\omega t+288°)} = \frac{0.733\epsilon^{-0.09\omega t}\sin(\omega t+242°38')}{1.224-0.946\cos(2\omega t+288°)}$$

The same denominator will appear in all of the terms and for convenience it will be replaced by a symbol $D(1)$, where

$$D(1) = 1.224 - 0.946\cos(2\omega t + 288°)$$

In order to use the equation for the sum developed in appendix B, it is necessary to get the first term of each series in the form of

$$\sin\,[n(\omega t+\theta_0)+\alpha]$$

The third term of ${}_1i_a$ can be written

$$0.687\epsilon^{-0.103\omega t}\sin(1.991\omega t+54°47') = 0.687\epsilon^{-0.103\omega t}\sin\,[1.991(\omega t+324°)+129°42']$$

where

$$\alpha = \phi - n(\theta_0) = 54°47' - 1.991\,(324°) = 129°42'$$

In similar manner for the fourth term

$$\alpha = 58°11' - 0.009\,(324°) = 55°16'$$

and

$$1.43\epsilon^{0.103\omega t}\sin(0.009\omega t+58°11') = 1.43\epsilon^{0.103\omega t}\sin\,[0.009\,(\omega t+324°)+55°16')$$

The third and fourth term series become respectively

$$\text{Third} = \frac{0.687\epsilon^{-0.10\omega t}}{D\,(1)}\times\frac{[\sin(1.991\theta+129°42')-0.473\sin(-0.009\theta+129°42')]}{D(1)}$$

$$\text{Fourth} = \frac{1.43\epsilon^{-0.103\omega t}[\sin(0.009\theta+55°16')-0.473\sin(-1.991\theta+55°16')]}{D(1)}$$

These two can be combined in the following manner.

$$0.687\ \angle 129°42' + 0.473\times 1.43\ \angle -55°16' = 0.061\ \angle 207°26'$$

$$1.43\ \angle 55°16' + 0.473\times 0.687\ \angle -129°42' = 1.109\ \angle 56°45'$$

and the combination of the third and fourth term series gives

$$\text{Third} + \text{fourth} = \frac{0.061\epsilon^{-0.103\omega t}\sin(1.991\theta+207°26')}{D(1)} + \frac{1.109\epsilon^{-0.103\omega t}\sin(0.009\theta+56°45')}{D(1)}$$

Substituting $\theta = \omega t + \theta_0$

$$\text{Third} + \text{fourth} = \frac{0.061\epsilon^{-0.103\omega t}\sin(1.991\omega t+132°31')}{D(1)} + \frac{1.109\epsilon^{-0.103\omega t}\sin(0.009\omega t+59°40')}{D(1)}$$

Then the complete expression for the armature current becomes

$$i_a = \frac{0.396\sin(\omega t+242°38')+0.733\epsilon^{-0.09\omega t}\sin(\omega t+242°\,38')}{1.224-0.946\cos(2\omega t+288°)} + \frac{0.061\epsilon^{-0.103\omega t}\sin(1.991\omega t+132°31')}{1.224-0.946\cos(2\omega t+288°)} + \frac{1.109\epsilon^{-0.103\omega t}\sin(0.009\omega t+59°40')}{1.224-0.946\cos(2\omega t+288°)}$$

The value of i_d can be found from each term of i_a by using the following equation.

$$i_d = \frac{2}{3}\,i_a\cos(\omega t+\theta_0) \tag{4b}$$

$$= \frac{2}{3}\times 0.745\sin(\theta-86°54')\cos\theta$$

$$= 0.248\sin(2\theta-86°54') - 0.248$$

Using equation $5b$, the i_d resulting from the first term of i_a and its series is

$$i_d = -0.248 + 0.248(1+b)[\sin(2\theta-86°54') + b\sin(4\theta-86°54') + b^2\sin(6\theta-86°54') + \text{etc.}]$$

$$I_{fd} = -\frac{X_{fad}}{X_{ffd}}\,i_d \tag{3b}$$

$$I_{fd} = -2.59\,i_d$$

As was shown in appendix B, the harmonics in I_{fd} are found by using only the bracketed terms of i_d.

The first term of the series is in the form

$$\sin\,[n(\omega t+\theta_0)+\alpha]$$

where

$n = 2$ $\alpha = -86°34'$ $b = 0.473$

$$\text{sum} = \frac{-2.59\times 0.248\times 1.473[\sin(2\theta-86°54')-0.473\sin(-86°54')]}{D(1)}$$

$$= \frac{-0.946\sin(2\omega t+201°6')-0.447}{D(1)}$$

In similar manner the sum of the next series becomes

$$-2.59\times\frac{1.38}{3}\times 1.473\epsilon^{-0.09\omega t}$$

$$= \frac{[\sin(2\theta-86°54')-0.473\sin(-86°54')]}{D(1)}$$

$$= \frac{-1.757\epsilon^{-0.09\omega t}\sin(2\omega t+201°6')-0.830\epsilon^{-0.09\omega t}}{D(1)}$$

For the third sum

$n = 2.991$ $b = 0.473$ $\alpha = 129°42'$

$$\text{sum} = \frac{-2.59\times\frac{0.687}{3}\times 1.473\epsilon^{-0.103\omega t}[\sin(2.991\theta+129°42') -}{D(1)}\ \frac{0.473\sin(0.991\theta-129°42')]}{D(1)}$$

For the fourth sum

$n = 1.009$ $b = 0.473$ $\alpha = 55°16'$

$$\text{sum} = \frac{-2.59\times\frac{1.43}{3}\times 1.473\epsilon^{-0.103\omega t}[\sin(1.009\theta+55°16') -}{D(1)}\ \frac{0.473\sin(-0.991\theta+55°16')]}{D(1)}$$

$$\text{Third sum} = \frac{[-0.875\sin(2.991\omega t+18°47')]\epsilon^{-0.103\omega t}}{D(1)} + \frac{[0.413\sin(0.991\omega t+90°47')]\epsilon^{-0.103\omega t}}{D(1)}$$

$$\text{Fourth sum} = \frac{[-1.82 \sin (1.009\omega t + 22°11')]\epsilon^{-0.103\omega t}}{D(1)} - \frac{[0.861 \sin (0.991\omega t + 265°49')]\epsilon^{-0.103\omega t}}{D(1)}$$

$$0.413 \ \angle 90°47' - 0.861 \ \angle 265°49' = 1.271 \ \angle 87°26'$$

Therefore

Third + fourth sums =

$$\frac{[-0.875 \sin (2.991\omega t + 18°47') - 1.82 \sin (1.009\omega t + 22°11')}{D(1)} + \frac{1.271 \sin (0.991\omega t + 87°26')]\epsilon^{-0.103\omega t}}{D(1)}$$

To these series must be added the 3 terms obtained from the original equations and the total field current becomes

$$I_{fd} = 1 + 1.84\epsilon^{-0.09\omega t} + 1.84\epsilon^{-0.103\omega t} \sin (0.991\omega t + 269°15') -$$

$$\frac{0.946 \sin (2\omega t + 201°6') + 0.447}{1.224 - 0.946 \cos (2\omega t + 288°)} + \frac{[1.757 \sin (2\omega t + 201°6') + 0.830]\epsilon^{-0.09\omega t}}{1.224 - 0.946 \cos (2\omega t + 288°)} -$$

$$\frac{[(0.875 \sin (2.991\omega t + 18°47') + 1.82 \sin (1.009\omega t + 22°11')]\epsilon^{-0.103\omega t}}{1.224 - 0.946 \cos (2\omega t + 288°)} + \frac{[1.271 \sin (0.991\omega t + 87°26')]\epsilon^{-0.103\omega t}}{1.224 - 0.946 \cos (2\omega t + 288°)}$$

Figure 1 is an oscillogram of a line-to-ground fault on a small wound-rotor induction motor, the rotor of which was excited by direct current. The calculated curve of armature current is shown as figure 2a, the calculated curve of field current is figure 2b.

Appendix D

LINE-TO-LINE SHORT CIRCUIT

$$x_2 = \sqrt{x_d' \, x_q'} \qquad (4a)$$

$$\begin{aligned} &= \sqrt{2.8 \times 0.21} = 0.75 \\ x_{qT}' &= 2.80 + 0.75 = 3.55 \\ x_{dT}' &= 0.21 + 0.75 = 0.96 \end{aligned}$$

$$b = \frac{3.55 - 0.96}{3.55 + 0.96} = \frac{2.59}{4.51} = 0.575$$

$$R = R_1 + R_2 = 2 \times 0.073 = 0.146$$

The constants for use in equations 10 are

$$\begin{array}{ll} R_{fd} = 1.0 & x_{dT} = x_{qT} = 3.55 \\ X_{afd} = 1.0 & X_{fad} = 81.7 \\ R = 0.146 & X_{ffd} = 31.5 \end{array}$$

The voltage shown on the oscillogram is that of phase b and since the equations require the angle between the direct axis and the axis of phase a

$$\theta_0 = (36° + 120°) = 156°$$

The solution obtained in a manner similar to line-to-ground case is

$$\begin{aligned} I_{fd} &= 1.0 + 2.88\epsilon^{-0.123\omega t} + 2.884\epsilon^{-0.101\omega t} \sin (0.991\omega t + 271°26') \\ {}_1i_{a1} &= 0.285 \sin (\omega t + 68°23') + 0.824\epsilon^{-0.123\omega t} \sin (\omega t + 68°23') + \\ &\quad 0.414\epsilon^{-0.101\omega t} \sin (1.991\omega t + 248°35') + \\ &\quad 0.699\epsilon^{-0.101\omega t} \sin (0.009\omega t + 248°26') \end{aligned}$$

But for a line-to-line fault

$$\begin{aligned} {}_1i_b &= -j\,1.732 \, {}_1i_{a1} = 1.732 \, {}_1i_{a1} \ \angle 270° \\ {}_1i_b &= 0.494 \sin (\omega t + 338°23') + 1.426\epsilon^{-0.123\omega t} \sin (\omega t + 338°23') + \\ &\quad 0.707\epsilon^{0.101\omega t} \sin (1.99\omega t + 158°35') + \\ &\quad 1.210\epsilon^{-0.101\omega t} \sin (0.009\,\omega t + 158°\,26') \end{aligned}$$

The angle $\theta_0 = 156$ degrees was reckoned on the basis of current in phase a and as the short circuit has been assumed to occur in phases b and c it is necessary to convert θ_0 over to phase b in order to obtain the correct series for i_b. Since i_b lags i_{a1} by 90 degrees, it is necessary to subtract 90 degrees from θ_0 to get the correct value to use for i_b.

$$\text{correct } \theta_0 = 156° - 90° = 66°$$

Now in a similar manner as was done in the line-to-ground case the summation of each series is found. Thus for the first term

$$0.494 \sin (\omega t + 338°23') = 0.494 \sin [(\omega t + 66°) + 272°23']$$

sum

$$= 0.494 \frac{\sin [(\omega t + 66°) + 272°23'] - 0.575 \sin [-(\omega t + 66°) + 272°23']}{1.342 - 1.170 \cos (2\omega t + 132°)}$$

$$= 0.494 \frac{0.420 \sin [(\omega t + 66°) - 80°59']}{1.342 - 1.170 \cos (2\omega t + 132°)} = \frac{0.208 \sin (\omega t + 345°1')}{1.342 - 1.170 \cos (2\omega t + 132°)},$$

and the total short-circuit current in phase b becomes

$$i_b = \frac{0.208 \sin (\omega t + 345°1') + 0.599\epsilon^{-0.123\omega t} \sin (\omega t + 345°1')}{1.342 - 1.170 \cos (2\omega t + 132°)} + \frac{0.064\epsilon^{-0.101\omega t} \sin (1.991\omega t + 248°22')}{1.342 - 1.170 \cos (2\omega t + 132°)} + \frac{0.798\epsilon^{-0.101\omega t} \sin (0.009\omega t + 161°1')}{1.342 - 1.170 \cos (2\omega t + 132°)}$$

Care must be taken in calculating the value of i_d.

$$i_d = \frac{2}{3} [i_a \cos \theta + i_b \cos (\theta - 120°) + i_c \cos (\theta + 120°)]$$

$$i_a = 0 \quad \text{and} \quad i_c = -i_b$$

$$\cos (\theta - 120°) = \cos (\omega t + \theta_0 - 120°)$$

where the θ_0 here refers to the current in phase a, but the θ_0 in the series must be the one with reference to phase b.

$$\begin{aligned} (\omega t + \theta_0 - 120°) &= (\omega t + 156° - 120°) = (\omega t + 66° - 30°) \\ &= (\omega t + \theta_0 - 30°) = (\theta - 30°) \end{aligned}$$

In order to use the value of $\theta_0 = 66$ degrees, the equation for i_d becomes

$$i_d = \frac{2}{3} [i_b \cos (\theta - 30°) - i_b \cos (\theta + 210°)]$$

For the first term of ${}_1i_b$

$${}_1i_d = \frac{2}{3} \times 0.494 [\sin (\theta - 87°37') \cos (\theta - 30°) - \sin (\theta - 87°37') \cos (\theta + 210°)]$$

$$= 2 \times \frac{0.494}{3} \times \frac{\sqrt{3}}{2} [\sin (2\theta - 87°37') - 1]$$

As was seen in the case of a line-to-ground circuit, only the part containing ($\sin 2\theta$) goes into making up the series.

Where

$$D(2) = 1.342 - 1.170 \cos (2\omega t + 132°)$$

in a similar manner the sum of the first term's series for the field current is,

$$\text{sum} = -\frac{\frac{0.494}{3}\times\sqrt{3}\times 2.59\times 1.575[\sin(2\theta-87°37')-0.575\sin(-87°37')]}{D(2)}$$

$$= -\frac{1.17\sin(2\omega t+44°23')-0.681}{D(2)}$$

And likewise in a manner similar to the line-to-ground case, adding on the part found from the 3-phase solution, the total expression for field current is found.

$$I_{fd} = 1.0 + 2.88\epsilon^{-0.123\omega t} + 2.884\epsilon^{-0.101\omega t}\sin(0.991\omega t + 271°26') - \frac{1.17\sin(2\omega t+44°23')+0.681}{1.342-1.170\cos(2\omega t+132°)} + \frac{[3.37\sin(2\omega t+44°23')+1.96]\epsilon^{-0.123\omega t}}{1.342-1.170\cos(2\omega t+132°)} - \frac{[1.68\sin(2.991\omega t+224°35')+2.87\sin(1.009\omega t+224°26')]\epsilon^{-0.101\omega t}}{1.342-1.170\cos(2\omega t+132°)} + \frac{[2.657\sin(0.991\omega t+89°25')]\epsilon^{-0.101\omega t}}{1.342-1.170\cos(2\omega t+132°)}$$

An oscillogram of a line-to-line fault on this same machine is shown in figure 3. The calculated values of armature and field currents are shown in figures 4*a* and 4*b*, respectively.

Appendix E

LINE-TO-GROUND SHORT CIRCUIT WITH REACTANCE IN ARMATURE

It was shown in appendix *A* that if there is any external reactance in the armature circuit, it must be added to x_d, x_2, and x_0

For an external impedance of 0.96 units the values of x_{qT}' become

$$x_{qT}' = 2.80 + 0.34 + 0.89 + 3(0.96) = 4.03 + 2.88 = 6.91$$
$$x_{dT}' = 0.21 + 0.34 + 0.89 + 3(0.96) = 1.44 + 2.88 = 4.32$$

The ratio *b* now becomes

$$b = \frac{6.91 - 4.32}{6.91 + 4.32} = \frac{2.59}{11.23} = 0.231$$

The resistance of the added reactance was 0.061 units but 3 times this resistance must be added in the same manner as 3 times the reactance was used.

$$R = 0.22 + 3(0.061) = 0.22 + 0.18 = 0.40$$

The constants for use in the equations are then

$$\begin{array}{lll} R_{fd} = 1.0 & x_{dT} = x_{qT} = 6.91 & \\ X_{afd} = 1.0 & X_{fad} = 81.7 & \\ R = 0.40 & X_{ffd} = 31.5 & \theta_0 = 5° \end{array}$$

The solution obtained is

$${}_1i_a = 0.432\sin(\omega t - 81°41') + 0.261\epsilon^{-0.051\omega t}\sin(\omega t - 81°41') + 0.129\epsilon^{-0.075\omega t}\sin(1.99\omega t + 102°25') + 0.564\epsilon^{-0.075\omega t}\sin(0.001\omega t + 97°21')$$

$$I_{fd} = 1.0 + 0.600\epsilon^{-0.051\omega t} + 0.600\epsilon^{-0.075\omega t}\sin(0.999\omega t+268°37')$$

Using the value of *b* as found above to calculate the additional harmonics, the complete solution becomes

$$i_a = \frac{0.333\sin(\omega t+280°18')+0.201\epsilon^{-0.051\omega t}\sin(\omega t+280°18')}{1.053-0.462\cos(2\omega t+10°)} + \frac{0.022\epsilon^{-0.075\omega t}\sin(1.999\omega t+180°)}{1.053-0.462\cos(2\omega t+10°)} + \frac{0.525\epsilon^{-0.075\omega t}\sin(0.001\omega t+98°)}{1.053-0.462\cos(2\omega t+10°)}$$

$$I_{fd} = 1 + 0.60\epsilon^{-0.051\omega t} + 0.60\epsilon^{-0.075\omega t}\sin(0.999\omega t + 268°37') - \frac{0.46\sin(2\omega t+283°19')+0.106}{1.053-0.462\cos(2\omega t+10°)} + \frac{[0.277\sin(2\omega t+283°19')+0.064]\epsilon^{-0.051\omega t}}{1.053-0.462\cos(2\omega t+10°)} - \frac{[0.137\sin(2.999\omega t+107°5')+0.60\sin(1.001\omega t+102°51')]\epsilon^{-0.075\omega t}}{1.053-0.462\cos(2\omega t+10°)} + \frac{[0.170\sin(0.999\omega t+89°24')]\epsilon^{-0.075\omega t}}{1.053-0.462\cos(2\omega t+10°)}$$

Figure 5 is an oscillogram of a line-to-ground fault with an external impedance in the armature circuit. Figures 6*a* and 6*b* show the calculated curves of armature and field current.

Appendix F

NOTATION

In general the symbolic notation used in this paper is the same as was used in the previous paper by the authors.

In this paper there is added, however, a sequence and harmonic notation. It seemed advisable to maintain the sequence notation usually used. A subscript letter after a current designates the phase, a number after that designates the sequence. If there is no number after the letter it designates the total current in that phase.

The harmonic notation is quite similar to the sequence notation except that the subscript is placed before the current. The number designates the frequency of the harmonic and if no number is used, it designates the total current including all of the harmonics.

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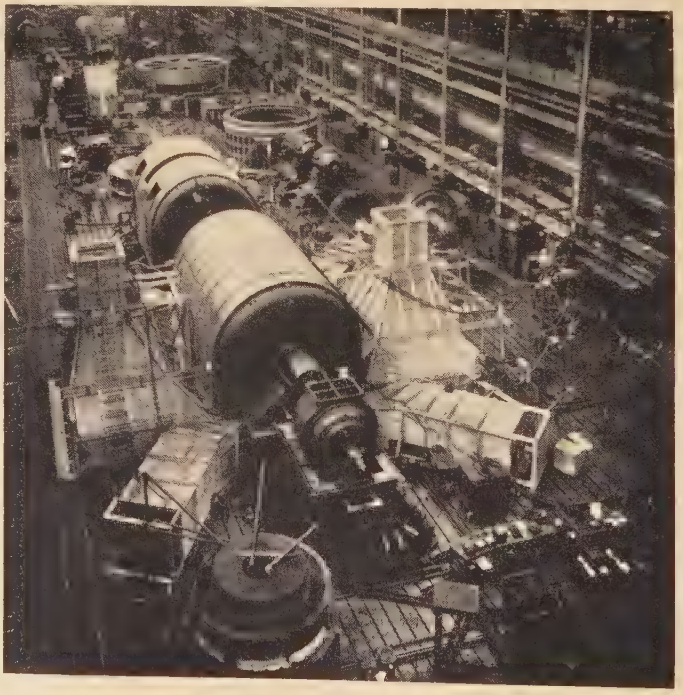

Single-Phase Induction-Motor Performance

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A COMMON procedure in the design of single-phase induction motors involves the determination of a stator winding to yield a desired maximum torque, followed by a check on motor performance. Yet in spite of the importance of the maximum torque value, little can be found in the technical literature concerning methods of predicting its magnitude, outside of those wherein the slip at which maximum torque occurs is substituted in the motor equations and the resulting maximum torque determined.[1] Inspection and trial from motor equations or the circle diagram are possible, but tedious, methods of approach.

A shorter and more direct method is given in this paper, offering the additional advantage of being largely in terms of the ratios of stator and rotor winding resistances to total leakage reactance. As such ratios are independent of the number of conductors used in the winding, analyses based on their use enable the designer to predict the winding necessary to yield a prescribed pull-out torque.

The equation for maximum torque will be derived here and its application and accuracy indicated.

With the winding fixed and the machine constants determined, it is frequently necessary to make a number of checks on the motor performance before it is constructed. Usually these checks involve only the calculation of no-load current and losses. Yet it is sometimes necessary to have performance curves (or several points thereon) while the machine is still in the design stage. Various analyses have been developed whereby the performance can be calculated from the machine constants. These analyses, whether based on the double-revolving-field theory, or the cross-field theory, take the form of circle or vector diagrams, equivalent networks, or analytical solutions. In any case they suffer the disadvantage of requiring tedious calculations, although improvements in simplifying the processes have been made by Branson, West,[6] Veinott[1] and others, with their tabulated procedures.

A process will be shown here which will enable the performance to be predicted readily, without complicated equations and with a precision greater than that of the resistance and reactance calculations. It is believed that a distinct need exists for this type of information.

It is possible to modify the cross-field equations for motor performance obtaining them in terms of ratios of machine constants. By assuming a series of values, the equations can be solved, the results plotted and hence made available for the analysis of any single-phase induction motor whose ratios of constants fall within the range prepared. Then for any speed, the primary current, power factor, watts input, output and efficiency, as well as less important values of counter electromotive force, rotor currents in each axis, and the rotor copper losses, can all be calculated by a comparatively simple process. Two methods of utilizing these curves will be shown, the first, being slightly more involved, requires one complex algebra calculation and is theoretically accurate except for the treatment of iron losses. (These cannot be covered with mathematical accuracy anyway.) The second method is shorter and easier to apply but with less theoretical accuracy. Calculations contrasting the 2 methods with test results and with standard analyses indicate that the shorter method is accurate enough for most routine work.

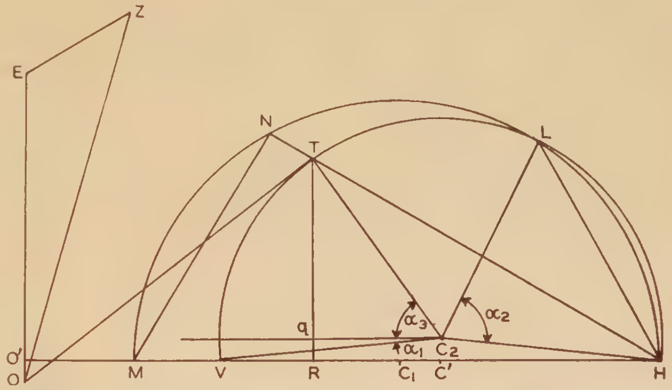

Figure 1. Circle diagram of the single-phase induction motor, based on the cross-field theory

Curve sheets will be shown here for 3 per cent slip only. Tabulated values suitable for preparing similar curves are given for other slips.

Derivation of Maximum Torque Equation

The Branson[2] application of the La Tour type of circle diagram is represented in figure 1. On this diagram it can be shown that the maximum input to the rotor occurs when the point T bisects the arc VL, the rotor input being

$$(OE) \times (TR)$$

(OE) represents the voltage E_c, less than the applied voltage by the stator-winding resistance drop.

The maximum rotor input is not exactly the point at which the maximum torque occurs, but the difference is negligible in the single-phase induction motor and the equations will be derived on such an assumption.

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted December 9, 1936; released for publication July 29, 1937.

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[1] For all numbered references, see list at end of paper.

To derive an expression for TR:

$$TR = C_2H \sin \alpha_3 + 0.5\, MV \frac{r_2}{X} \tag{1}$$

Let

$$\frac{r_2}{X} = p$$

The center C_2 is above the base by the distance $0.5\, MVr_2/X$

$$MV = O'M \frac{K_r}{2 - K_r} = \frac{E_c(1 - K_r)K_r}{X(2 - K_r)} \tag{2}$$

Then

$$0.5\, MV \frac{r_2}{X} = \frac{p}{2} \frac{E_c}{X} \frac{1 - K_r}{2 - K_r} K_r \tag{3}$$

$$C_2H = \sqrt{(C_2C')^2 + (C'H)^2} \tag{4}$$

$$VH = \frac{E_c}{X} \frac{K_r}{2 - K_r} \tag{5}$$

$$C_2H = \sqrt{\left(\frac{E_c}{2X} \frac{K_r}{2 - K_r}\right)^2 + \left(\frac{p}{2} \frac{E_c}{X} K_r \frac{1 - K_r}{2 - K_r}\right)^2} \tag{6}$$

$$\sin \alpha_3 = \frac{\cos \dfrac{\alpha_2}{2}}{} = \sqrt{1 - \sin^2 \frac{\alpha_2}{2}} \tag{7}$$

$$\sin \frac{\alpha_2}{2} = \frac{p}{\sqrt{p^2 + 1}} \frac{2 - K_r}{\sqrt{1 + p^2(1 - K_r)^2}} \tag{8}$$

Then from equations 2, 6, 7, and 8:

$$TR = \frac{E_c}{X} \cdot \frac{K_r}{2(2 - K_r)} \times \left\{ \sqrt{\left[1 + p^2(1 - K_r)^2\right] \left[1 - \frac{p^2(2 - K_r)^2}{(p^2 + 1)[1 + p^2(1 - K_r)^2]}\right]} + p(1 - K_r) \right\} \tag{9}$$

Define tr such that $TR = (E_c/X)tr$. Values of tr for various ratios of r_2/X and values of K_r are plotted in figure 2.

In order to apply the correction for the stator resistance drop it is necessary to determine the ratio of E_c to the applied voltage V. To do this it is necessary to know the magnitude and position of the current OT. This depends obviously upon $O'R$ as well as TR and an expression for $O'R$ will be obtained, applicable when the point T bisects the arc VL. Under this condition:

$$O'R = \frac{E_c}{X} \cdot \left[1 - \frac{1}{2} \frac{K_r}{2 - K_r} - \frac{p}{2\sqrt{1 + p^2}}\right] \tag{10}$$

$O'O$ is the current component supplying the core losses; this can be neglected with little error, as it will make but slight modification in the magnitude of the current at the point of maximum torque, and still less modification in the ratio of voltages for which this value is to be used.

Define $o'r$ such that $O'R = (E_c/X)o'r$. Values are plotted in figure 2.

Let $r_1/X = p_1$. Then, accounting for the stator winding resistance drop:

$$V = E_c[1 + p_1(tr - jo'r)]$$

$$\left(\frac{E_c}{V}\right)^2 = \left(\frac{OE}{OZ}\right)^2 = \frac{1}{[(1 + p_1tr)^2 + (p_1o'r)^2]} \tag{11}$$

Let the expression in brackets be Q'. Then the final expression for maximum secondary input is

$$V^2 \left(\frac{OE}{OZ}\right)^2 \frac{tr}{X} = V^2 \frac{tr}{Q'X} \tag{12}$$

As the last step it is necessary to fix the relationship between secondary input, secondary output, and torque.

Secondary input = output + F + Fe (C) + Secondary Cu (M) + Secondary Cu (C)

Where (C) and (M) represent cross and main axes, respectively.

Let

$$a = \frac{\text{Total secondary copper losses}}{\text{Output} + F + Fe\ (C)}$$

Then

$$\text{Output} = \frac{\text{Secondary input}}{(1 + a)} - [F + Fe\ (C)] \tag{13}$$

It has been shown by Veinott[3] that the ratio a used above is equal to

$$\frac{1 - S^2}{S^2} + \frac{2(r_2/X_0)^2}{[(1 - S^2) - (r_2/X_0)^2]S^2} \tag{14}$$

This can also be written:

$$\frac{1 - S^2}{S^2} + \frac{2[p(1 - K_r)]^2}{[(1 - S^2) - p^2(1 - K_r)^2]S^2} = a \tag{15}$$

Where S is the ratio of actual revolutions per minute to synchronous revolutions per minute. A value for S at the point of maximum torque, as a function of r_2/X is plotted in figure 3. This is slightly modified from Vei-

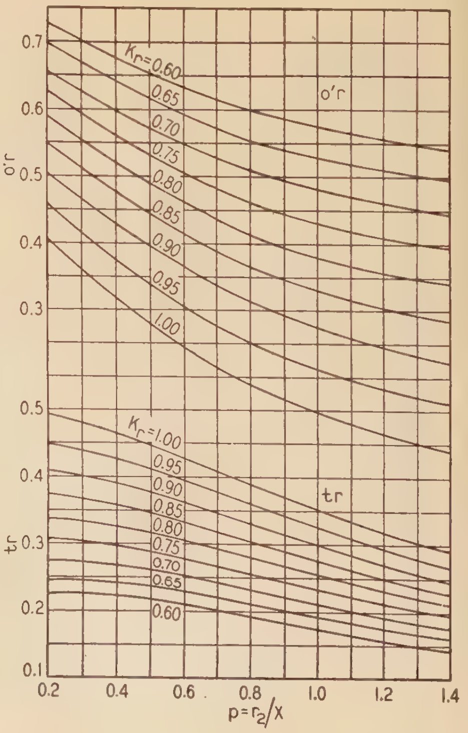


Figure 2

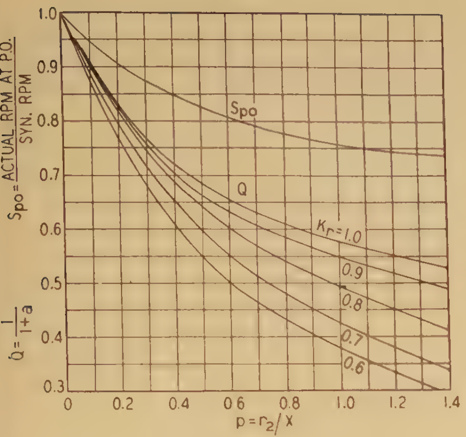
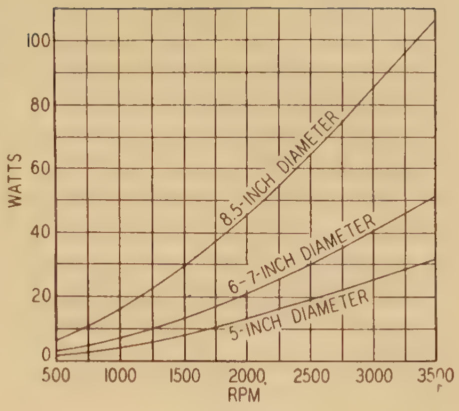


Figure 3

Figure 4. Friction and windage losses classified by outside diameter of stator. Sleeve bearings



nott's curve, which he obtained from the Branson circle diagram. Sumec[4] also gives a formula for this relationship but it applies to greatly restricted conditions.

Values of $1/(1 + a)$ (denoted as Q) are shown in figure 3. As the final expression for maximum torque in ounce-feet:

$$\text{P. O. T.} = \frac{112.6}{\text{Syn. rpm}}\,\frac{1}{S_{po}}\left[\frac{V^2}{X}\,tr\,\frac{Q}{Q'} - (F + Fe\,(C))\right] \qquad (16)$$

The above equation is applicable when the windings are fixed and the constants are known. When the winding is to be determined in order to give a prescribed maximum torque, it should be such as to give the value of total leakage reactance calculated below. Then:

$$X = \frac{V^2\,tr\,Q/Q'}{\left[\dfrac{\text{P. O. T.} \times \text{Syn. rpm} \times S_{po}}{112.6} + F + Fe\,(C)\right]} \qquad (17)$$

In using the above equation to design a single-phase motor of the required maximum torque, it is necessary to estimate the friction and windage losses as well as the iron loss of the cross axis. In making such estimates, data on similar machines are useful, but in the absence of such data table I is of value for iron-loss assumptions.

Table I. Approximate Value of Cross-Axis Iron Losses

60 cycles:	Below 0.5 horsepower	$Fe\,(C) = 100 \times$ horsepower
	0.5 to 1.5 horsepower	$Fe\,(C) = 50 \times$ horsepower
25 cycles:	Below 0.5 horsepower	$Fe\,(C) = 75 \times$ horsepower
	0.5 to 1.5 horsepower	$Fe\,(C) = 40 \times$ horsepower

Probable friction and windage losses as a function of speed and outside stator diameter, are shown in figure 4.

It will be noted that S_{po}, tr, Q, and Q' are functions of r_1/X, r_2/X, and K_r, each of which is independent of the actual number of conductors used in the stator winding as long as the saturation factor remains the same. A higher saturation factor reduces K_r.

Then since the total leakage reactance X can be calculated from equation 17 in order for the motor to yield the designed pull-out torque, the number of series conductors necessary are:

$$C = \sqrt{\frac{X \cdot 10^8}{2\pi f P_L}} \qquad (18)$$

where P_L = the equivalent permeance of the leakage flux paths (slot, zig-zag and end connection) corrected for winding pitch and distribution. Methods for determining it are well known, but a recent collection of data combining the work of various investigators has been prepared by the present writers,[5] along with processes for calculating r_1/X, r_2/X and K_r from machine dimensions.

The development given above involves no approximations aside from (1) those inherent in this type[2] of the circle diagram, (2) the neglect of iron-loss component in locating the position of the stator current, and (3) the slight error in the assumptions from which the speed relationship was obtained.[3] That these errors are not serious can be seen from the contrasted results given in table II. Values were obtained from routine tests and were subject to uncorrected temperature effects and slight errors in constants.

Table II. Contrasted Test and Calculated Values

Pull-out torque in ounce-feet

Motor	P.O.T. Test	P.O.T. Calculated
$^3/_4$-horsepower 4-pole 60-cycle	107.00	104.0
$^1/_4$-horsepower 4-pole 50-cycle	43.50	44.7
$^1/_4$-horsepower 4-pole 60-cycle	37.75	36.8
$^1/_4$-horsepower 4-pole 60-cycle	37.2	35.4
$^1/_6$-horsepower 2-pole 25-cycle	30.0	32.0
$^1/_{10}$-horsepower 4-pole 40-cycle	25.5	25.9
$^1/_8$-horsepower 2-pole 25-cycle	23.0	23.0
$^1/_6$-horsepower 4-pole 60-cycle	20.5	19.2

As seen, the test and calculated results agree well within commercial requirements, particularly if X can be calculated to sufficient precision.

An example of calculation is given in appendix I.

Basis for Performance Calculations: Cross Field Theory

No attempt will be made to give the derivation of the cross-field theory on which the analysis is based, but since some differences exist between the work of different writers it will be necessary to identify the view-point taken

The reader is referred to a paper by H. R. West,[6] in which he shows 3 fundamental equations for primary and

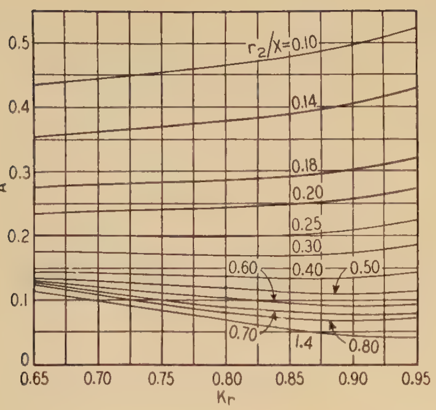


Figure 5. Current constants for performance

secondary voltage relationships in the single-phase motor. These are based on the assumptions:

1. Sine-wave distributions of magnetomotive force, and uniform air-gap permeances.

2. Angle of hysteretic lag between flux and magnetomotive force is neglected. (An approximate method of overcoming the small error caused by this assumption will be shown.)

3. The rotor conductors, in generating a speed electromotive force, are considered to cut not only the mutual flux but the rotor leakage flux as well. This assumption follows Arnold as against that of Steinmetz.[8] The evidence available indicates that the former basis is the more accurate, as signified by West.

4. The leakage reactance of stator and rotor will be assumed to be equal when in equivalent terms. The errors due to this are in general negligible.

EQUATIONS

The determination of main and cross-axis rotor currents, as well as the stator current, is always complicated because the necessary simultaneous equations are three in number, and contain constants and variables as complex numbers. As a practical method of attack the local primary drop is neglected and a solution for the rotor values, which depend upon the counter electromotive force, is obtained. This also fixes the primary current, and the stator drop correction is applied later in a manner to be shown.

The 3 equations as given by West (several symbols changed) are:

$$V = I_1r_1 + jI_1x_1 + jX_m(I_1 - I_y) \tag{19}$$

$$0 = -jX_m(I_1 - I_y) - S(X_m + x_2)I_x + I_y\,(r_2 + jx_2) \tag{20}$$

$$0 = j(X_m + x_2)I_x - SX_m(I_1 - I_y) + Sx_2I_y + r_2I_x \tag{21}$$

It follows then that:

$$I_1 - I_y = I_\phi$$

$jI_\phi X_m$ = the counter electromotive force, E

Solving equations 20 and 21 for the 2 rotor currents: Main axis,

$$I_y = E\,\frac{r_2 + jX_0(1 - S^2)}{{r_2}^2 - x_2(1 - S^2)X_0 + j\,(r_2X_0 + r_2x_2)} \tag{22}$$

Cross axis,

$$I_x = E\,\frac{-jr_2S}{{r_2}^2 - x_2(1 - S^2)X_0 + j(r_2X_0 + r_2x_2)} \tag{23}$$

If the effect of the cross-axis core loss, which is considered as a rotor load (equal to slightly less than half of the total core loss) is taken into account, these equations would become (based on Arnold[8]):

$$I_y = E\,\frac{[(1 - S^2)(Z_0 + Z_2) + r_2S^2]}{(Z_0 + Z_2)(Z_2 - jS^2x_2) + jr_2x_2S^2} \tag{22a}$$

$$I_x = E\,\frac{-jr_2S}{(Z_0 + Z_2)(Z_2 - jS^2x_2) + jr_2x_2S^2} \tag{23a}$$

Where

$$Z_2 = r_2 + jx_2$$

$$Z_0 = \frac{1}{\dfrac{1}{r_f} + \dfrac{1}{jX_m}}$$

That is, the cross-axis core losses take place in an equivalent resistance, r_f; magnetizing reactance and core-loss resistance being represented by a series impedance Z_0. The use of these latter equations involving the additional variable r_f would too greatly complicate the set of curves given here and will be neglected. Then Z_0 becomes equal to $-jX_m$.

Table III. Contrasted Calculated and Test Results

Motor used as example in appendix

Item	Method I	Method II	Test
Slip	0.03	0.03	
I_1	3.16	3.03	3.25
Power factor	0.595	0.619	0.585
Input	207.2	205.2	209.0
E	90.5	91.0	
I_y	2.04	2.045	
I_x	1.145	1.15	
Output	0.158 horsepower	0.159	0.1585
Efficiency	0.566	0.578	0.565
Revolutions per minute	1,164	1,164	1,150

Regardless of the magnitudes of the various constants in these equations, the values of I_y and I_x can always be obtained as functions of E/X for all possible combinations of motor constants. Once such data are plotted they can then be used for practically all designs.

Determination of Curve Data

By substituting the values $r_2 = pX$ and $X_0 = X/(1 - K_r)$ in equations 22 and 23, they become:

$$I_y = \frac{E}{X}\left[\frac{p + j\dfrac{1 - S^2}{1 - K_r}}{p^2 - \dfrac{1 - S^2}{2(1 - K_r)} + j\left(\dfrac{p}{2} + \dfrac{p}{1 - K_r}\right)}\right]$$

$$= \frac{E}{X}(A - jB) \tag{24}$$

$$I_x = \frac{E}{X}\left[\frac{-jpS}{p^2 - \dfrac{1 - S^2}{2(1 - K_r)} + j\left(\dfrac{p}{2} + \dfrac{p}{1 - K_r}\right)}\right]$$

$$= \frac{E}{X}G \tag{25}$$

The values of the "current constants" A, B, and G, are functions of r_2/X, K_r, and speed. For any value of speed, curves can be drawn as shown in figures 5 and 6. These curves were prepared by assuming values of p and K_r for various slips and plotting the resultant current constants.

Calculation of Performance, First Method

The fundamental equations neglect the effect of any iron loss in the cross axis. This will be considered here by adding an iron-loss current component to the in-phase part of the stator current.

Table IV. Calculation Methods Contrasted

1/4 horsepower, 4-pole, 60-cycle, 110-volts

	Double Revolving Field	Cross Field Theory			
Item	Equivalent Circuit	Curves* of Method II	Modified[10] Arnold Method	Equivalent Circuit	Branson's Circle[2] Diagram
Speed	1,700	1,700	1,700	1,700	1,700
I_1	3.94	3.65	3.825	3.83	4.05
Power factor	0.734	0.762	0.737	0.722	0.745
Input	318.0	306.7	310.0	305.0	320
Output	197.0	203.3	199.0	203.2	198
Efficiency	0.620	0.66	0.642	0.665	0.630
Losses	121	103.4	111	101.8	122
Synchronous watts	208.4	215	211	215	210

* A, B, and G were read for this speed from curves plotted against slip, rather than the set of curves given here, for which this slip is not included.

$$\text{In-phase current} = \frac{E}{X}A + \frac{Fe}{E}$$

$$= \frac{E}{X}(A') \tag{26}$$

where

$$A' = A + \frac{FeX}{E^2}$$

Similarly the magnetizing current should be added to the out-of-phase component, then:

$$\text{Out-of-phase current} = \frac{E}{X}(B + 1 - K_r) = \frac{E}{X}U$$

Then the primary current is

$$\frac{E}{X}(A' - jU) = I_1 \tag{27}$$

$$\text{Stator impedance} = r_1 + jx_1 = X(p_1 + j\,0.5)$$

$$\text{Applied voltage } V' = E[1 + (A' - jU)(p_1 + j\,0.5)]$$

As this voltage will likely be different from the applied, a ratio V_{rated} to V' is used to correct the assumed value of counter electromotive force.

With the counter electromotive force known, equations 24, 25, and 27 can be used to obtain the respective currents; input, output, efficiency, and power factor being figured in the usual manner as shown in appendix II. It will be seen that this process has been based simply upon the use of plotted solutions of rotor current.

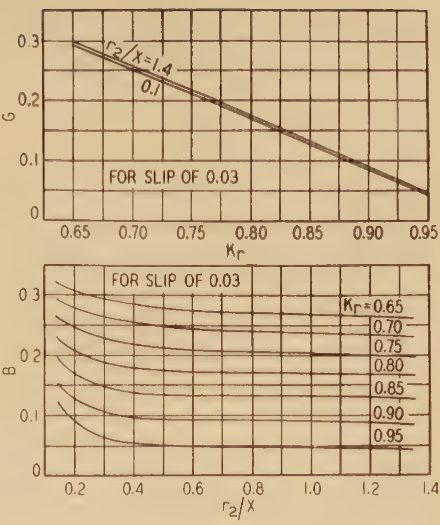


Figure 6. Current constants for performance

Second Method

In nearly all cases of normal design, it was found that little error is introduced in the vicinity of rated-load values, by assuming that the counter electromotive force differs from the applied voltage by the stator impedance drop considered algebraically. The in-phase component of stator current caused by considering the iron loss, will be neglected (as was done by West). Then:

$$I_1Z_1 = E\sqrt{(A^2 + U^2)(p_1^2 + 0.25)} \tag{28}$$

and

$$I_1 = \frac{V}{X}\,\frac{\sqrt{A^2 + U^2}}{[1 + \sqrt{(p_1^2 + 0.25)(A^2 + U^2)}]} \tag{29}$$

Procedure: For the motor values of r_2/X and K_r, at the slip for which performance is desired, A, B, and G are calculated or read from the curves.

Calculate

$$U = B + 1 - K_r$$

$$C' = \sqrt{A^2 + U^2}$$

$$D = 1 + C'\sqrt{p_1^2 + 0.25}$$

Then

$$I_1 = \frac{V}{X}\,\frac{C'}{D}$$

$\text{Power factor} = \dfrac{A}{C'}$ (See appendix III for correction based on iron loss)

$\text{Power input} = V \times I_1 \dfrac{A}{C'}$ (See appendix III for correction based on iron loss)

$$\text{Counter electromotive force} = \frac{V}{D} = E$$

$$\text{Rotor input} = E^2\frac{A}{X}$$

$$I_y = \frac{E}{X}\sqrt{A^2 + B^2}$$

$$I_r = \frac{E}{X}G = I_1\frac{G}{C'}$$

Rotor losses $= r_2 (I_y^2 + I_x^2) + (F \& W) + Fe$

The iron loss *Fe* can be treated differently and need not be included above.

Rotor output = Input − losses

By this process all significant performance items can be obtained at any speed for which curves are prepared. Simple arithmetical ratios are used, complex numbers being completely avoided.

Some comment should be made upon the treatment of core loss. Theoretically the cross-axis core loss (slightly less than half of the total) should appear as rotor load and be subtracted from the output. The subtraction of the total core loss (assumed constant at all loads), from the rotor output is not theoretically justified but produces fair results except in extreme cases. The reduction of core loss with load increase, due to a reduction in counter electromotive force, can be made in either method shown above, inasmuch as the counter electromotive force is known. Then since rotor currents and hence rotor input, were calculated with the assumption of no core loss, the addition of a reduced core loss to the stator input would appear to be a more consistent treatment than subtraction from the rotor output.

Table V. Calculated Values of A²

r_2/X =		0.2	0.25	0.30	0.40	0.50	0.60	0.80	1.00	1.40
Slip = 0.02										
K_r =	0.95	0.190	0.154	0.128	0.096	0.076	0.065	0.049	0.041	0.030
	0.90	0.182	0.148	0.123	0.095	0.077	0.067	0.053	0.044	0.038
	0.85	0.177	0.144	0.122	0.095	0.080	0.071	0.060	0.053	0.050
	0.80	0.173	0.141	0.122	0.096	0.084	0.077	0.070	0.065	0.065
	0.75	0.169	0.141	0.122	0.099	0.089	0.084	0.080	0.079	0.084
	0.70	0.167	0.141	0.123	0.103	0.094	0.091	0.091	0.094	0.104
Slip = 0.04										
K_r =	0.95	0.370	0.296	0.255	0.193	0.150	0.129	0.100	0.080	0.059
	0.90	0.349	0.278	0.238	0.180	0.143	0.121	0.097	0.078	0.061
	0.85	0.335	0.270	0.230	0.177	0.145	0.125	0.102	0.085	0.073
	0.80	0.327	0.265	0.229	0.178	0.149	0.130	0.112	0.100	0.090
	0.75	0.320	0.262	0.228	0.179	0.153	0.135	0.124	0.114	0.108
	0.70	0.310	0.257	0.225	0.179	0.158	0.140	0.133	0.127	0.124
Slip = 0.05										
K_r =	0.95	0.454	0.375	0.314	0.234	0.190	0.160	0.122	0.097	0.066
	0.90	0.435	0.359	0.301	0.228	0.183	0.155	0.122	0.100	0.076
	0.85	0.420	0.345	0.292	0.221	0.180	0.157	0.125	0.105	0.088
	0.80	0.405	0.335	0.285	0.216	0.181	0.160	0.132	0.114	0.100
	0.75	0.392	0.330	0.283	0.217	0.181	0.161	0.140	0.125	0.116
	0.70	0.383	0.326	0.283	0.220	0.183	0.165	0.149	0.137	0.135

The neglect of this core loss results in calculated power factors that are inclined to be low, and more accurate results can be obtained by multiplying power factor, as calculated, by the ratio.

$$\frac{\text{Stator input with core loss}}{\text{Stator input without core loss}}$$

Illustrative examples and comparative results are given in appendix III.

Conclusion

Calculations shown in tables III and IV are taken from design-sheet data in which later tests indicated a fair, but not exact, agreement between predicted motor constants and the values as measured. Under these conditions discrepancies between final test performance and predicted performance include the results of small design-sheet errors. Examples are available in which better agreement exists between predictions and tests but those included here were selected as about representative.

Designers are well aware that in dealing with small single-phase induction motors, predictions of performance cannot be made with the consistent accuracy possible, say, with large polyphase machines. This is true regardless of the theoretical accuracy of the method employed; the discrepancies arise largely from the nonconstant nature of the so-called constants. For this reason the accuracy of the calculation methods given here can best be investigated by comparison with other established analysis. Such data are given in table IV.

Table VI. Calculated Values of B

r_2/X =		0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.4
Slip = 0.02									
K_r =	0.95	0.066	0.058	0.051	0.048	0.047	0.046	0.046	0.046
	0.90	0.109	0.101	0.096	0.092	0.090	0.090	0.089	0.088
	0.85	0.150	0.144	0.141	0.137	0.133	0.132	0.131	0.130
	0.80	0.191	0.184	0.180	0.176	0.174	0.171	0.170	0.167
	0.75	0.233	0.226	0.220	0.214	0.210	0.207	0.203	0.199
	0.70	0.270	0.261	0.255	0.248	0.244	0.240	0.233	0.225
Slip = 0.04									
K_r =	0.95	0.113	0.080	0.060	0.048	0.048	0.047	0.047	0.046
	0.90	0.160	0.120	0.105	0.094	0.092	0.091	0.090	0.089
	0.85	0.190	0.155	0.145	0.135	0.132	0.130	0.129	0.127
	0.80	0.225	0.195	0.185	0.175	0.171	0.170	0.170	0.164
	0.75	0.255	0.235	0.222	0.213	0.210	0.209	0.205	0.197
	0.70	0.295	0.273	0.260	0.249	0.245	0.243	0.238	0.225
Slip = 0.05									
K_r =	0.95	0.145	0.097	0.076	0.058	0.051	0.048	0.047	0.045
	0.90	0.188	0.135	0.114	0.098	0.094	0.092	0.090	0.088
	0.85	0.224	0.175	0.155	0.138	0.133	0.131	0.130	0.129
	0.80	0.257	0.207	0.186	0.177	0.173	0.170	0.167	0.163
	0.75	0.286	0.245	0.224	0.210	0.207	0.200	0.198	0.193
	0.70	0.323	0.281	0.263	0.245	0.239	0.232	0.227	0.217

Symbols and Factors

V = applied voltage
r_1 = stator-winding resistance
r_2 = rotor resistance in stator terms
x_1 = stator-winding leakage reactance
x_2 = rotor leakage reactance in stator terms
X_m = mutual or magnetizing reactance in stator terms
$X_0 = X_m + x_1$
= magnetizing reactance for air gap and primary leakage fluxes
$K_r = \dfrac{X_0 - X}{X_0}$
$X \cong x_1 + x_2$
$= x_1 + \sqrt{K_r}\, x_2$
F = watts, friction and windage
Fe = watts, core loss
$E_c = V - I_1 r_1$ (as vectors)
E = counter electromotive force
I_1 = primary current
I_y = rotor current of the main axis in stator terms
I_x = cross-axis rotor current in stator terms
S = per cent of synchronous speed

S_{po} = per cent of synchronous speed at which maximum torque occurs

$p = r_2/X$

$p_1 = r_1/X$

$$tr = \frac{K_r}{2(2 - K_r)} \times \left\{ \sqrt{\left[1 + p^2(1 - K_r)^2\right]\left[1 - \frac{p^2(2 - K_r)^2}{(p^2 + 1)[1 + p^2(1 - K_r)^2]}\right]} + p(1 - K_r) \right\}$$

This is plotted in figure 2.

$$o'r = \left\{1 - 0.5 \cdot \frac{K_r}{2 - K_r} - \frac{p}{2\sqrt{1 + p^2}}\right\}$$

This is plotted in figure 2.

$$Q' = [(1 + p_1\, tr)^2 + (p_1\, o'r)^2]$$

$$Q = \frac{1}{1 + a}$$

$$a = \frac{\text{Total secondary copper losses}}{\text{output} + F + Fe\ (C)}$$

This is plotted in figure 3.

C = series conductors of the stator winding

P_L = equivalent permeance of the leakage flux paths

A = in-phase portion of the "current constant"

$$A - jB = \left\{ \frac{p + j\left(\dfrac{1 - S^2}{1 - K_r}\right)}{p^2 - \dfrac{1 - S^2}{2(1 - K_r)} + j\left(\dfrac{p}{2} + \dfrac{p}{1 - K_r}\right)} \right\}$$

This is plotted in figures 5 and 6.

$$G = \left\{ \frac{-jpS}{p^2 - \dfrac{1 - S^2}{2(1 - K_r)} + j\left(\dfrac{p}{2} + \dfrac{p}{1 - K_r}\right)} \right\}$$

This is plotted in figure 6.

$$A' = A + \frac{Fe\,X}{E^2}$$

$$U = (B + 1 - K_r)$$

$$C' = \sqrt{A^2 + U^2}$$

$$D = 1 + C'\sqrt{p_1^2 + 0.25}$$

Appendix

I. Example of Maximum Torque Calculations. Machine data are taken from the example given by Veinott[1] for a single-phase induction motor, 110 volts, 4 poles, 60 cycles.

$r_1 = 3.8$ $r_2 = 4.65$ $X = 8.3$ $K_r = K_p^2 = 0.929$

$F + Fe\ (C) = 19$ watts

$r_1/X = p_1 = 0.458$ $r_2/X = p = 0.56$

From curves:

$tr = 0.392$, $o'r = 0.342$, $Q = 0.65$, $S_{po} = 0.817$, $(1 + p_1\, tr)^2 = 1.387$ $(p_1\, or)^2 = 0.0246$ $Q' = 1.387 + 0.0246$ or 1.4116

Table VII. Approximate Values of G

Slip =	0.02	0.04	0.05
K_r = 0.95	0.049	0.049	0.047
0.90	0.093	0.091	0.090
0.85	0.135	0.131	0.130
0.80	0.175	0.171	0.168
0.75	0.215	0.210	0.205
0.70	0.250	0.245	0.240

$$\text{P. O. T.} = \frac{112.6}{1800 \times 0.817}\left[\frac{110^2 \times 0.392 \times 0.65}{8.3 \times 1.411} - 19\right]$$

$= 18.6$ ounce-feet. This result is the same as that of Veinott.

II. Performance Calculations, First Method. Single-phase induction motor, $^1/_6$-horsepower, 110 volts, 6 poles, 60 cycles.

$r_1 = 3.95$ ohms $X = 9.72$ ohms $r_1/X = p_1 = 0.406$

$r_2 = 3.07$ ohms $K_r = 0.862$ $r_2/X = p = 0.315$

Friction and windage (F and W) = 9 watts; iron loss (Fe) = 29.4 watts; from curves, for a slip of 0.03, $A = 0.170$, $B = 0.138$, $G = 0.123$

$$B + 1 - K_r = U = 0.276$$

$$\sqrt{A^2 + B^2} = 0.219$$

Assume a counter electromotive force of 100 volts.

$$\frac{Fe\,X}{E^2} = 0.026 \qquad A' = 0.196$$

$$V' = 100[1 + (0.196 - j\,0.276)(0.406 + j\,0.5)] = 121.78 - j\,1.68 = 121.8$$

$$\text{Correction} = \frac{110}{121.8} \text{ or } 0.905$$

$$I_1 = \frac{90.5}{9.72}(0.196 - j\,0.276) = 1.82 - j\,2.58 \text{ or } 3.16$$

$$I_y = \frac{90.5}{9.72}\,0.219 = 2.04 \qquad I_y^2 r_2 = 12.72 \text{ watts}$$

$$I_x = \frac{90.5}{9.72}\,0.123 = 1.145 \qquad I_x^2 r_2 = 4.02 \text{ watts}$$

$$\text{Rotor input} = EI_y \cos\theta_2 = 90.5 \times 2.04 \times \frac{0.17}{0.219} \text{ or } 143.5 \text{ watts.}$$

Rotor output = 143.5 − rotor losses = 143.5 − (12.72 + 4.02 + 9.0)
= 117.8 watts or 0.158 horsepower

$$\text{Core loss} = \frac{\text{counter electromotive force}}{\text{applied voltage}}\,(Fe)$$

$$= \frac{90.5}{110} \times 29.4 \text{ or } 24.3 \text{ watts.}$$

Stator input = Rotor input + Core loss + Stator copper loss
= 143.5 + 24.3 + 39.4 or 207.2 watts.

$$\text{Power factor} = \frac{207.2}{3.16 \times 110} \text{ or } 0.595$$

Alternate method, neglecting small angle between applied volts and counter electromotive force

$$\text{Power factor} = \frac{1.82}{3.16} \text{ or } 0.575$$

$$\text{Efficiency} = \frac{117.8}{207.2} \text{ or } 0.566$$

III. Performance Calculations, Second Method. Same motor used in II with a slip of 0.03.

$$A = 0.17 \qquad B = 0.138 \qquad G = 0.123 \qquad U = 0.276$$

$$C' = \sqrt{A^2 + U^2} = 0.324$$

$$D = 1 + C'\sqrt{p_1^2 + 0.25} = 1.209$$

$$I_1 = \frac{V}{X}\frac{C'}{D} = 3.03$$

$$\text{Counter electromotive force} = \frac{V}{D} = 91.0$$

$$\text{Rotor input} = E^2\frac{A}{X} = 144.7 \text{ watts}$$

$$I_y = \frac{E}{X}\sqrt{A^2 + B^2} = 2.045 \qquad I_y^2 r_2 = 12.85 \text{ watts}$$

$$I_x = \frac{E}{X}G = 1.15 \qquad I_x^2 r_2 = 4.05 \text{ watts}$$

$$\begin{aligned} \text{Rotor output} &= \text{Input} - \text{rotor losses} \\ &= 144.7 - (12.85 + 4.05 + 9.0) \\ &= 118.8 \text{ watts or } 0.159 \text{ horsepower} \end{aligned}$$

$$\text{Core loss, corrected as before} = 24.3 \text{ watts}$$

$$\begin{aligned} \text{Stator input} &= \text{Rotor input} + \text{Core loss} + \text{Stator copper loss} \\ &= 205.2 \text{ watts} \end{aligned}$$

$$\text{Efficiency} = \frac{118.8}{205.2} \text{ or } 0.578$$

$$\text{Power factor} = \frac{205.2}{3.03 \times 110} \text{ or } 0.619$$

Alternate calculation method for input and power factor:

$$\text{Input, neglecting core loss} = VI_1\frac{A}{C'} \text{ or } 175 \text{ watts}$$

$$\text{Corrected by adding core loss} = 199.3 \text{ watts}$$

$$\text{Power factor, core loss neglected} = \frac{A}{C'} = 0.526$$

$$\begin{aligned} \text{Power factor corrected for core loss} &= \frac{A}{C'}\,\frac{\text{Input with core loss}}{\text{Input without core loss}} \\ &= 0.526\,\frac{199.3}{175} \text{ or } 0.60 \end{aligned}$$

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The Engineer's English

IN AN ARTICLE entitled "The Importance of English to an Engineer," appearing in *The Electric Journal* for February 1937, pages 81–2, W. W. Palmer challenged engineers to assume as an obligation to themselves and to society, in which they are playing a rôle of increasing importance, the aim of becoming fluent speakers, more convincing writers, to the end of becoming better salesmen of the ideas constantly being created by their inventive minds.

Mr. Palmer believes that the engineer's inability to express himself forcefully is not an inherent characteristic, but a product of the environment and tradition in which he has received his professional training; and to strengthen that contention he traces the various stages in the evolution of an engineer, showing the factors at each stage contributing to the inarticulateness of the technical man. Quoting from the article, ". . . there is no objection to an engineer being given a cultural education, but the old idea that he must learn to write and speak a couple of dead languages and study the lives, characteristics, and vaporing of poets and writers of all ages has been overstressed."

Continuing, the author execrates the manner in which the engineering graduate attempts to obtain employment: "The employment manager, knowing engineers, expects their written applications to be evasive on their weak points and exaggerated on what they consider their strong ones. The general attempt is to prove that they can fill any position. . . . . . No specific and sound reasons are given as to why the writer's services will pay dividends. The writer does not intentionally evade, but he is simply incapable of properly presenting his case in writing. . . . . . Few engineers sell their services. They are hired. The distinction is reflected in their salaries."

After the young engineer has been hired "lack of practical experience necessitates that at first he work among those whose educational advantages have been inferior to his own. From them he frequently acquires the use of profanity for emphasis and superlatives for impressiveness. Enunciation and precision are forgotten. This loss is reflected in his work."

"Years later we find this engineer writing important purchase specifications that will be misinterpreted; dictating letters in which the ideas to be conveyed are smothered beneath an avalanche of words. To him punctuation is a stenographic function. At this age the engineer's work has become so specialized that few in, or outside of, his group of associates are capable of correcting or criticizing. . . . He speaks a highly technical language that normally isolates him from general conversations. He becomes a lone thinker but at the same time he must be able to interpret the results of his thoughts to less technical thinkers, such as his executives."

"We like to feel that engineers have been, and always will be, true pioneers in the advance of civilization. On the other hand, we know that those who lead best are often misunderstood, inadequately appreciated, and poorly compensated. The blame is our own when we do not make ourselves understood."

D-C Machine Stray-Load-Loss Tests

By VICTOR SIEGFRIED
ASSOCIATE AIEE

Synopsis

Two test methods for the determination of stray load losses in d-c machines are described. Application of the loading-back principle permits measurements to a high degree of accuracy. A technique is developed for stabilizing no-load losses so that consistency of results is improved. Results of tests of several machines are presented, together with an analysis of the relation of loss to operating conditions of the machine.

IN THE MEASUREMENT of efficiency of d-c machinery, stray load loss is generally receiving insufficient consideration. Its omission from conventional efficiency tests has resulted principally from the difficulty experienced in measuring it accurately. Variability in performance of the commutator apparently is the factor which has caused failure to obtain consistent results in previous attempts to measure stray load loss.[1–5] Consequently the accurate determination of d-c machine losses and efficiency has lagged behind that of other types of machinery.

Methods of controlling the performance were devised and applied to d-c machines in the course of work on stray load loss of induction machines,[6] in which it was found possible to repeat conditions and measurements almost at will. The present investigation was undertaken to extend this experience and information to the testing of other machines, and to demonstrate the applicability of the loading-back type of test to d-c machines.

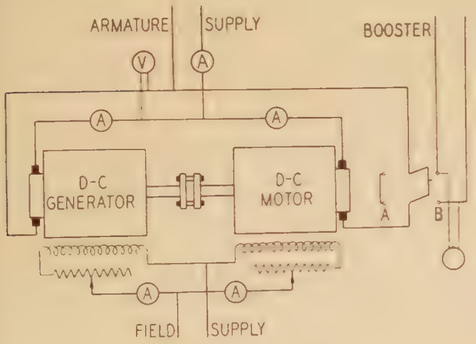

Figure 1. Diagram of connections for load-back tests

The load-back test is a familiar tool used extensively for loading machines and conducting heat runs. Two machines are direct-connected and operated from a common source with current circulating between them, one machine acting as a motor to drive the other as a generator. Slight adaptations which are necessary for applying it to the measurement of stray load loss are discussed. Two types of load-back test which are most practicable and easily performed commercially are described, together with the technique which should permit obtaining consistent results. The variation of stray load loss with some of the operating conditions is investigated, and curves are presented to show these effects graphically.

Summary

This investigation of stray load loss in d-c machines outlines methods whereby that loss may be measured, and presents the results of application of some of those methods to several groups of machines as described in table I. Several definite conclusions may be drawn from this work:

1. Stray load loss is not a negligible factor in d-c machine performance and efficiency. It is in the order of magnitude of other losses and must receive due consideration.

2. Stray load loss can be measured, and should be measured in preference to the assignment of a value from an empirical formula.[4,5]

3. Stray load loss was found by test to range from 0.8 to 1.8 per cent of full-load input in several groups of machines.

4. Controlling factors of the amount of stray load loss are armature current, magnetic field strength, and machine speed.

5. The familiar load-back test can be adapted to the measurement of stray load losses in d-c machines. It can be made with the assurance of reasonably consistent results if proper technique be employed to eliminate variations in no-load losses during the test.

6. Two methods of loading-back appear to be the most practicable for commercial tests, from the standpoint of accuracy, convenience, and amount of equipment involved. The choice of test to be used will depend upon the equipment available to the tester.

7. The "electrical loss supply" method with a booster (Hutchinson method[7]) has the desirable feature of keeping armature currents nearly equal in both machines and of permitting loading of machines under the same conditions of excitation. It has the disadvantage of requiring an additional generator to serve as a booster. It involves input to the system from 2 electrical sources, thus doubling the chance for error in measurements.

8. The "electrical loss supply" (Kapp[7]) method has the simplest circuit available for the measurement of stray load loss. It can be performed with a minimum of equipment, although greater convenience may be achieved with 2 independent sources of voltage for armature and field circuits respectively.

9. Having only one source of supply for the losses, the Kapp method has the advantage of high accuracy and sensitivity.

10. Load-back methods usually require identical machines, but if one machine is available which has been calibrated previously for its stray load loss, any other machine of similar rating may be loaded-back upon it.

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted May 4, 1937; released for publication August 30, 1937.

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The author is indebted to Professor Theodore H. Morgan for his advice and encouragement and for the opportunity to do this work, and to the manufacturers who donated machines for the tests.

[1] For all numbered references, see list at end of paper.

Nature of Stray Load Loss

By definition, stray load loss is a residual loss that cannot be determined from "conventional performance" data taken at no load. It is the increase in loss that results from loading of the machine by increase in armature current. The flux distortion accompanying increases in armature current gives rise to this loss through far-reaching effects. The iron loss is changed; eddy currents occur in the conductors due to transverse fluxes and to tooth saturations; tooth-frequency losses are changed to some extent; and short-circuit loss in the coils undergoing commutation is changed. These effects are dependent in turn upon the amount of armature current; the frequency of flux pulsations and hence the speed of the machine; and upon the saturation of the iron at no load.

Table I. Machines Tested for Stray Load Loss

Machines	Rating	Voltage	Current (Amperes)	Speed (RPM)	Stray Load Loss (Per Cent of Full-Load Input)
1 and 2	15 hp	230	55.6	1,750	1.2
3 and 4	10 hp	110	79	1,700	1.6
5 and 6	10 hp	220	38.2	1,750	0.95
7	10 hp	230	38	1,750	0.85
8 and 9	7.5 kw	160	47	1,800	1.8

Information as to the manner in which these factors influence the loss is helpful in devising test methods. It is desirable and usually necessary to include measurements of the loss at other than only normal operating speed, armature current, or excitation. This investigation therefore attempts to determine some of these relationships in order to bring out the significance of certain procedures required in some of the tests available.

Load-Back Tests

The load-back test has long been used for loading machines in heat runs and to a certain extent for efficiency measurements. It was originated as early as 1886,[8] and several variations have been proposed since then. A brief discussion will serve to identify some of the methods and their salient features. More complete descriptions are to be found in the engineering literature.[7]

KAPP METHOD

In their simplest form, load-back tests are made with rotors of 2 machines coupled or belted together. Both armatures are connected to a common source of power, the machines being loaded-back upon each other by means of current circulating between them. The loading is controlled by adjustment of the internal generated voltage of either or both machines, the one with the lower excitation becoming the motor. Assuming for purposes of this discussion that the field circuits are separately excited, the entire loss in this combination of machines is supplied electrically from the line, and includes the no-load losses of both machines plus the additional losses occasioned by the assumption of load. The machine acting as a motor thus supplies all of the losses through its circuit, and hence has the larger armature current. The difference between machine currents, however, decreases as the size of the units increases.

This method, attributed to Kapp and also called the "electrical loss supply" method uses the circuit shown in figure 1 when the switch in the motor circuit is in the *A* position. The total losses are determined from readings of the line ammeter, which indicates automatically the difference in machine currents. This test provides for measurements of high accuracy and considerable sensitivity to small changes in loss. Its principal disadvantage is that the 2 machines cannot be operated at the same magnetic saturation.

HUTCHINSON METHOD

If a booster generator be placed in series with the armature of one machine, the loading-back of the system may be accomplished through adjustment of the booster voltage in such a way as to cause different voltages to exist at the terminals of the 2 machines. The connection for this is shown in figure 1 with the switch at *B*. Current thus will circulate without the necessity for adjustment of the internal generated voltage of either machine. The power input to the system from the booster will be approximately equal to the copper losses in the 2 machines. Mechanical losses will be supplied substantially as in the Kapp test, from the common voltage source. Thus the armature currents under load conditions will be nearly equal, and the field excitations will be exactly the same in both machines. Only one additional instrument is needed, a voltmeter indicating the booster voltage where it is impressed on the load-back system.

This type of test is known as the Hutchinson method. It operates the machines under quite desirable conditions, but does require an additional generator in the testing equipment. The total loss input from which stray load loss is calculated comes from 2 sources, however, which necessitates additional care in the reading of all instruments.

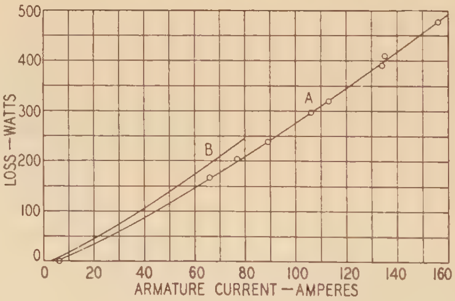


Figure 2. Stray load loss of machines 1 and 2

A—Loss as measured by load-back tests

B—Loss for one machine

Excitation normal

Speed—1,800 rpm

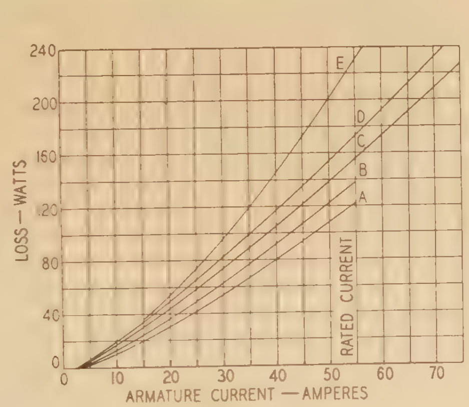
OTHER METHODS

There are other types of load-back test which could be used, if the greater complication of circuits and possible loss of accuracy did not make them unsatisfactory for commercial stray-load-loss measurements. The Blondel opposition method, in which an auxiliary motor connected to the set is used to supply the rotation losses and a booster to supply the electrical losses, does operate both machines under identical conditions. It is better suited to laboratory use than to commercial tests. Another method, called the "mechanical loss supply" method, uses the auxiliary motor coupled to the machines to supply all losses, the machines being operated independently of any common source. The adjustment of loading must be made entirely by manipulation of field current, thus making it undesirable as a test for stray load loss. The same objection applied to the Potier method, in which all the losses are supplied by a booster generator in series with both machines.

Load-Back Test Procedure

In order to adapt the load-back test to the measurements of stray load loss, certain simplifications can be made in the usual test procedure employed. The requirements as to conditions to be maintained are different. Values of the loss are desired over the ordinary working range of armature current, speed, and excitation. It is therefore unnecessary to operate the machine with rated terminal voltage. Thus speed control may be had by variation of the armature voltage, and independently of field current adjustments. As loss in the field circuit is not included in the calculations for stray load loss, it is possible for it to be supplied from an independent source at constant voltage.

Figure 3. Variation of stray load loss with excitation, machines 1 and 2



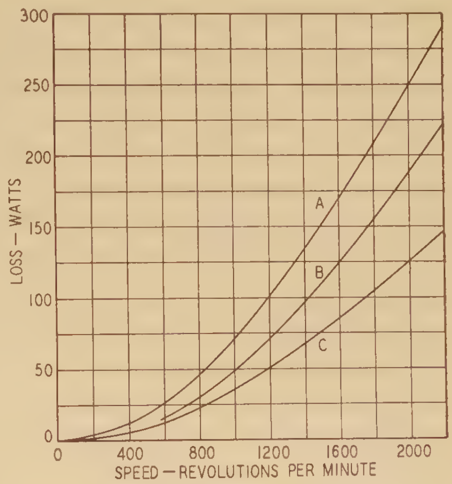
Speed—1,800 rpm
Excitation:
A—129 per cent normal
B—114 per cent normal
C—Normal
D—86 per cent normal
E—28 per cent normal

The control of all losses during a load-back test is very important to the success of the test. Since the stray load loss results from the difference between total measured loss and the known losses, variation of any of these during a run may cause considerable error in the final result.

The most important item requiring control is the brush-friction loss. This loss ordinarily is quite erratic, and causes the no-load loss of which it is a part to be unstable. In these tests it is not necessary that no-load losses duplicate those for ordinary working conditions, but merely that they be held constant during measurements of other quantities. Control of this brush-friction loss may be had by stabilizing surface conditions of the commutator. This is done through a judicious application of paraffin to the commutator to form a thin lubricating film. Paraffin is applied in quantities only sufficient to reduce the friction loss and consequently the no-load loss to a minimum, as indicated by input to the machines for a particular speed and excitation. For short periods of time, the no-load loss will then remain practically constant, but will gradually increase as the film of paraffin wears off. Frequent checks of the no-load loss are quite essential to consistent results in all tests. Where curves of no-load losses with various field currents and speed will be necessary as in tests conducted according to the Kapp method, they will be useful only so long as the original conditions are repeated.

Figure 4. Variation of stray load loss with speed, machines 1 and 2

Excitation—Normal
Armature current:
A—70 amperes
B—55 amperes (rated)
C—40 amperes



The use of paraffin on the commutator is practically indispensable for stray load loss testing. It is doubtful whether this treatment should be recommended for general practice, however. As to the effect on brush-contact resistance, paraffining does not make it abnormally large. Apparently carbon particles become imbedded in the thin film and assist in maintaining good commutation.

Accurate determination of copper loss in the machines is also very important to the stray-load-loss test. Actual values of terminal-to-terminal drop must be measured instead of being calculated on the basis of assumed constant values of brush-contact drop. Care must be taken to include the drops in all parts of the machine circuits back to the junction where applied voltage is measured.

Proper specification of the magnetic saturation also is necessary, particularly where machines have compound field windings. Total ampere-turns determine the field strength; so it is better for purposes of this test to omit the series windings and retain only the shunt and commutating windings. More stable operation of machines is obtained as a result of this procedure. Brushes must be set carefully in the neutral position to eliminate undue loss in the commutated coils.

Test of Machines

Measurements were made for the stray load loss of several sets of machines as described in table I. All machines are stock models of their type. Machines 3, 4, and 7 are of the same type as 5 and 6 except older and of different voltage ratings. Number 7 was loaded back on number 5. All machines were mounted on a solid base, carefully aligned and direct-connected through flexible couplings.

Electrical connections were made as shown in figure 1. A variable voltage supply was provided for the armatures, and a fixed voltage supply for the shunt fields. The booster, used in all tests except on machines 8 and 9, was a variable voltage machine of suitable capacity. Instruments were calibrated against primary standards. Speeds were measured by stroboscope where feasible, otherwise by tachometer, so that it was convenient to consider 1,800 rpm as the normal speed of all machines.

As a preliminary to the testing of each pair of machines, the brushes were set in the neutral position as found by running the machines successively under full load in opposite directions at the same speed. The brushes were worn in and the commutator was lubricated with paraffin until a stable value of no-load loss was reached. Curves of no-load loss were then taken for various speeds and excitations.

The sequence of operations in the Hutchinson test was first to warm the machines by running them under load. Then both were motored and a setting made so that currents were equal in both machines with excitation adjusted to a specified value. The value of the no-load loss was read, the switch in figure 1 thrown to the *B* position, and the booster voltage increased in gradual steps to increase the loading, speed being maintained at a desired value by adjustment of the supply voltage. A final reading was then taken of the no-load loss and the machines were shut down quickly to obtain the terminal-to-terminal drop. On some sets of machines, other data were taken for loading the machines by the Kapp method, with the motor switch always in the *A* position.

Results of Tests

The data obtained in these tests were reduced to stray load loss by subtracting all of the known losses from the power input of the line, and of the booster when used. Curves shown in figures 2–4 are for the test of machines 1 and 2 by the booster (Hutchinson) method and are typical of results of tests on all machines. Figure 2 shows the loss under normal conditions of speed and excitation. Curve *A* shows the experimental points, which give the loss for both machines acting together, plotted as a function of the arithmetical sum of armature currents. The curve *B*, for one machine by itself, is obtained by a graphical separation method.[9] Briefly, the first approximation of curve *B* is found by plotting one-half of the ordinate of *A* against half of its abscissa. Using the actual ratio of machine currents, this approximation is used to reconstruct a curve similar to *A*. One-fourth of the difference between the reconstruction and the experimental curve is used as a correction by which to find the true curve of *B*. Actually, in all of the tests performed the armature currents were sufficiently close in value, and such was the nature of the variation of the loss that very little correction was necessary.

The change of stray load loss with armature current, other conditions being constant, follows a smooth progression, with the loss increasing at a greater rate for larger currents. This is what might be expected, but it is interesting to note that it does not increase with the square of the current, as might first be supposed.

VARIATION WITH EXCITATION

In figure 3 are shown curves for the loss of one machine alone with various field currents. These curves are similar to curve *B* of figure 2, and are those derived from experimental points by graphical separation. From them, it is apparent that stray load loss increases as the excitation or magnetic saturation is reduced. This effect was observed to differing degrees in all machines tested. The explanation is probably that flux distortion has farther-reaching effects in producing stray load loss as the initial saturation of the iron is reduced. For small variations in excitation around normal conditions, the changes in loss seem to be nearly proportional. Curves *A–D* show results typical of all machines.

This relationship makes it advisable to manipulate field currents, when required in the conduct of the stray-load-loss test by the Kapp method, in such a way that as the excitation of one machine is reduced to make it assume load as a motor, that of the other is increased in like proportion. In this way, the error introduced by changing the saturation as machines are loaded is minimized.

Attempts were made in tests of machines 1 and 2 to measure the loss for extremely low excitations, in the order of 25 per cent of normal field current. Under such conditions, however, one factor which affects the measurement becomes more apparent, and machines are operating so low on the saturation curve that an exact specification of the degree of excitation is not possible. The loss itself can be measured with the same accuracy as at normal conditions, but the initial total magnetization conditions are dependent not alone upon field ampere-turns but also upon the residual magnetism or hysteresis of the iron as a result of changing armature flux. Thus, for the same values of shunt field current, different curves will be obtained depending upon whether armature currents are being increased or decreased. This effect is present at all saturations to some extent, but becomes of smaller importance as the excitation approaches normal. It does contribute to the difficulty of manipulation in the tests, and may account for inconsistencies in results which have not been explainable heretofore. Curve *E* in figure 3 shows the loss for approximately 30 per cent of normal excitation.

VARIATION WITH SPEED

The variation of stray load loss with speed is shown in figure 4 for several values of machine current, excitation being held constant for all cases. The loss is seen to increase rapidly with speed. This is to be expected from the fact that the frequency at which the stray load losses occur is proportional to speed, and that the loss should therefore be a function of speed to some power between 1 and 2. For the curves shown in figure 4, the exponent is approximately 1.9. Other machines showed exponents from 1.2 to 1.6.

Summary of Results

To sum up the results of the tests, values are given in table I of the stray load loss for each machine under normal conditions of load, excitation, and speed, expressed in per cent of input at full load. These figures show that stray load loss differs with the type of machine.

For some of the machines, tests for stray load losses were conducted by both the Kapp and Hutchinson methods. Good agreement was shown in the results, and final figures are given as an average value of the 2 tests. The methods are fundamentally the same, although by means of the booster it is possible to keep field currents constant at all times. In the Kapp test, manipulation of the field current is necessary to make the machines take load, with the result that the 2 machines will be operating under somewhat different saturation conditions. The error caused by this effect can be minimized by following the procedure suggested above. This offers no serious handicap to the measurement of stray load loss by this method and results will be well within any tolerance for accuracy in the final value of stray load loss.

Emphasis should be made here that it is not always necessary to have 2 identical machines for a load-back test if one machine has previously been subjected to a test for its stray load losses. The requirement of 2 identical machines is only necessary for the purpose of making proper division of the stray load loss between them.

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Central-Station Voltages for Lighting

OF THE POPULATION in the United States receiving central-station service, 98 per cent is now supplied at a nominal standard voltage of 115 or 120, according to an article by G. S. Merrill (A'08, M'12) head of the section of lighting economics of the incandescent lamp department, General Electric Company, Cleveland, Ohio, appearing in the August 1937 issue of the Edison Electric Institute *Bulletin*, pages 327–8. The trend has been slowly toward the adoption of the higher voltages. In 1923, 36.3 per cent of the population using central-station service obtained power at 110 volts, 40.9 per cent used 115 volts, and 19.4 per cent used 120 volts. In 1937 only 1.8 per cent of this population is supplied by 110-volt circuits, but 52.1 per cent of the users obtain power at 115 volts, and 46.0 per cent at 120 volts. From 1923 until 1933 the use of 115-volt service increased, but since 1933 its use has declined and 120-volt service has gained in favor at the expense of both of the other standard voltages. This trend is attributed to the increasing use of light, heat, and power on residential circuits and the use of 3-phase 4-wire 120/208-volt networks in commercial areas.

In the interest of good lighting service, public utility companies and lamp manufacturers in general are trying to encourage the use of lamps of which the labeled voltage corresponds to the average voltage at which they are operated. Although the amount spent by customers for electric energy and for lamps decreases if the lamps are operated at lower voltage, the light output diminishes more rapidly than the operating expense, and the customer pays more per unit of light.

In areas where part or all of the business section is supplied at 120 volts and the residential section at 115, the problem of keeping properly rated lamps in use throughout the community is very difficult, and the re-establishment of a single standard voltage for the whole community is presumed to be best accomplished by increasing the voltage on the existing 115-volt circuits to 120. Poor voltage regulation throughout an area also contributes to undervoltage operation of lamps, because lamps properly rated for operation along the high-voltage branches of the network must be provided, and experience has indicated that these high-voltage lamps find their way into many low-voltage sockets. The same difficulty is experienced along the boundary line between systems operating at different voltages.

The author suggests that the establishment of a single standard utilization voltage of 120 throughout the United States not only would remove a great obstacle to the operation of lamps at correct voltage, but also would contribute to improvements in the design, production, distribution, and use of appliances on central-station circuits. The article contains a comprehensive statistical survey of the utilization voltages employed in various states in convenient tabular form, and one figure delineating the upward trend of these voltages during the last 14 years.

Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

ON THIS and the following 29 pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the sessions on communication and research, insulation co-ordination, general power applications, power generation and electrical machinery, power transmission, and vibration and balance at the 1937 AIEE summer convention, Milwaukee, Wis., June 21–25. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers. Other discussion of summer convention papers will be published as it is made available.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at any AIEE meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to AIEE headquarters 33 West 39th Street, New York, N. Y.

Application of Spill Gaps and Selection of Insulation Levels

Discussion of a paper by H. L. Melvin and R. E. Pierce published in the June 1937 issue, pages 689–94, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937.

J. H. Foote and **J. R. North** (Commonwealth & Southern Corporation, Jackson, Mich.): This paper gives an excellent presentation of the application of gaps as protective devices co-ordinated with insulation levels.

The authors point out that the protected level varies with the time of incidence of the surge, the protected level or surge voltage allowed on apparatus being higher with decrease in time, i.e., with increased steepness of wave front, higher voltages are impressed. With this in mind, the statement of page 689 that, "A spill gap provides a definite voltage discharge level . . ." may be misleading. Should not the word "curve" or "characteristic" be substituted for the word "level" which ordinarily brings to mind one numerical value remaining uniform under varying conditions.

Figure 1 is clear and should be widely studied by the users of gapped equipment. Much misunderstanding might thereby be eliminated relative to the protection afforded by gaps.

We cannot agree with item 1 under conclusions, "Spill gaps . . . afford dependable protection to equipment and insulation against failure from lightning" unless qualified. Gaps are particularly adapted for the protection of insulation in air, such as bushings and insulators, rather than for solid or laminated forms of insulation. The authors point out the necessity of extremely close gap spacing when used for the protection of solid insulation against fast waves.

Data as to allowable spacings from the operating standpoint are interesting and valuable. Evaluation of service interruptions occasioned by the operation of gaps must be made by each operator to suit existing conditions. In view of the wide range of gap settings used at the same operating voltage in different locations, we would like to ask the authors to give correlating data regarding apparatus insulation strengths and neutral grounding conditions in order that these gap settings may be further studied. It would be very helpful if this explanatory data could include the following information for each of the locations cited:

Original insulation tests specified for apparatus protected.

System neutral effectively grounded or ungrounded.

Ratio of zero sequence impedance to positive sequence impedance under maximum fault conditions.

M. H. Lovelady (Central Power and Light Company, San Antonio, Texas): Melvin and Pierce are to be commended for the abundance of information contained in their paper "Application of Spill Gaps and Selection of Insulation Levels."

The table I in the paper tabulates the operating record of spill gaps in Texas. Although not stated, these apparently are mostly straight grounded gaps without fuses or expulsion tubes. The table shows a remarkably small percentage of gap operations and it would be of interest to know whether means were used definitely to determine whether or not the gaps operated.

A south Texas company has perhaps more repeater type fused gaps in operation than any of those companies to which the authors had access to operating records and a condensed report covering the operating record of these gaps is of interest.

A total of 185 repeater-type fused gaps have been installed to date and 200 more will be installed this year, however only 103 single-phase installations were in operation during the entire lightning season of 1936 and the tabulation is confined to these 103 installations.

The authors conclusions with respect to minimum permissible gap settings are of interest and bear out operating experience of the south Texas company. Excessive operations due to switching surges have not been experienced with gap settings of a lower ratio than those mentioned in the paper. The settings at all installations have a ratio of normal line to neutral voltage approximately as follows; for 69-kv systems 1.35, for 38-kv systems 1.87, for 22-kv systems 2.2, and for 12-kv systems 2.85. All of the installations are on solidly grounded-neutral systems.

More information regarding the frequency of operation of close-set gaps would be of interest. The table in this discussion shows the number of operations that took place between inspections. All installations were inspected after each lightning disturbance.

Thirty of the installations are at attended stations and it is of interest to note that operators have on several occasions reported that the gaps spilled over without system follow up current, indicating that the surge was dissipated during the instant of very low or zero system voltage.

Line Voltage (Kilovolts)	Gap Setting (Inches)	Number of Installations	Operations Between Inspections				Total Operations
			No. of Tubes				
			1	2	3	4	
66	6	60	80	23	8	8	182
38	4	16	30	15	2	2	89
22	2	9	19	4	2	0	33
12	1.25	18	17	7	2	0	37
Total		103	146	49	14	10	341

All of the fused gaps except 9, are installed on transformers directly at the bushing and in series with the transformer fuse. The other 9 are installed on the line side of the oil circuit breakers at the bushing, at a station where 3 69-kv lines enter the station. The station being located at a point where lightning is particularly severe. This station also has fused gaps located at the transformer bushings. The station is protected by overhead ground wires over the the station and extending one mile out on each of the 69-kv circuits.

It is interesting to note that on 2 occasions the gaps at the transformers operated when none of the line gaps operated and that there were 10 operations of the line gaps when the transformer gaps did not operate. On no occasion did both sets of gaps operate simultaneously and on no occasion did more than one gap operate on the same phase. Of the 10 line gap operations, 8 were on the same line, the remaining 2 operations taking place one on each line.

Only 2 of the 341 operations were accompanied by blowing of transformer fuses and those were probably due to faulty fuses as a number of operations have taken place at the same locations without fuse failures.

During the entire period there were no tube failures on the fuse gaps and no tube flashovers. There were several failures of devices to trip the next tube into operating position. These failures however were due to mechanical difficulties and the trouble has now been remedied.

Nine of the operations were caused by birds shorting out the gaps, a condition not considered serious as the operations caused no system disturbance and the loss of one tube out of 4 is not serious.

Only 2 of the operations occured during periods when there was no visible lightning and these are the only 2 operations that may be attributed to switching surges.

It is of interest to note from the tabulation that of the 10 reports of all 4 fuses operating between inspections, 9 of these occurred at end of the line stations. It is also interesting to note that average operations per unit per year for the system is 3.4, while average operations per unit per year for end of the line installations is 6.5.

Based upon the above record, the company now plans to change all of the end of the line installations to 8 fuse repeaters instead of 4.

Although the repeater-type fuse gaps have only been in operation on the Texas system for a little more than a year, single-shop fuse gaps have been used for several years. The transformer failure record at points where the single-shop fuse gaps had been installed lead to the installation of the repeater type. A comparison of transformer failure records at some of these points is of interest.

At one 38-kv station 3 transformers failed in 1930 and one more in 1931. Fused gaps were installed in 1932 and there have been no more failures.

At a 69-kv station, 2 transformers failed in 1931 and 2 more in 1932. Fused gaps were installed after the 1932 failure and there have been no more failures.

At another 69-kv station, 2 transformers failed in 1932, 2 in 1935, and 2 more in the early part of 1936. After the 1936 failure, fused gaps were installed and there have been no more failures.

H. L. Rorden (Ohio Brass Company, Barberton, Ohio): It is unfortunate that the volt-time characteristics of insulation failures are not susceptible to mathematical analysis. The problem of insulation coordination depends upon volt-time characteristics, which must be determined empirically. Because of this and the vast amount of data that has been accumulated from a great number of sources, it is difficult to draw reasonable conclusions. Differences of opinion also complicate the problem, so that the absolute performance of dielectrics under high-voltage surges is still not completely understood. Since volt-time performance plays such a prominent part in the general scheme of co-ordination, it seems timely to point out some characteristics which may not be generally understood and which may lead to erroneous conclusions if overlooked.

It should be of interest to all working in this field to know that the volt-time characteristics of insulation failures in general, are not as definite or precise as we may like to have them. As an illustration, it is frequently possible to obtain time lags at minimum impulse flashovers which differ by 100 per cent or more in time without a measurable difference in voltage. In flashover tests of a simple rod gap for instance, successive flashovers may range from about 8 microseconds to more than 20 microseconds with identically the same voltage applied. It is apparent that the phenomenon that produces such flashovers is very unstable and cannot be measured as an exact time. It would seem more logical that these data be plotted as a band. This band becomes narrow rapidly with increasing overvoltages, but is still measurable in the very short time range. In this short time range the curve may be very steep with respect to voltage, so that in spite of the narrow band a considerable range of voltage may obtain at exactly the same time to flashover. The band, therefore, is broad as a function of time at minimum flashovers and is broad as a function of voltage at the high overvoltages. In some instances it is found that a variation of 100 per cent in voltage may obtain at identically the same time to flashover. This range is not common, but in some tests it does obtain. It is apparent that to assume an average and plot a line to represent such volt-time characteristics, may be misleading and result in the adoption of margins which may be insufficient.

Another point of interest is in connection with so-called "flat" volt-time characteristics such as are illustrated in figure 1 of the transformer subcommittee report, figure 3 of the arrester levels paper by Messrs. Foote and North, and figure 1 of the spill gap paper by Messrs. Melvin and Pierce. Flashovers which are not dependent upon the formation of corona to complete the breakdown, are usually said to have a flat volt-time characteristic. An example of this is the sphere gap. In nonuniform dielectric fields such as in the rod gap where long times to flashover may obtain, the curve is said to be sloping. A little further clarification on these phenomena is in order. It would seem probable that the conception of a flat curve originated from the fact that analytically no flashover may be considered as a flashover at infinity. Therefore, once a minimum voltage was reached, the curve was continued without change in voltage to infinity. This is a misnomer, since it is impossible to obtain long time lags in sphere-gap flashovers. The flashover of spheres, being almost independent of corona, will occur very quickly or not at all. Thus the volt-time curve of a sphere-gap tested with the $1^{1}/_{2}$ x 40 wave ceases to exist as soon as it becomes flat. Ordinarily it is not possible to obtain flashovers of a sphere-gap with this test wave in more than 3 microseconds. Therefore, the entire curve is that part which curves upward in times less than 3 microseconds. This point is of interest because it has been assumed in some instances that lower flashovers of gaps, irrespective of time, indicates better protection. It is apparent that if a gap or insulation having a "flat" characteristic is to be protected by another gap, it would be useless to provide protection that might flashover in 10 or 15 microseconds when a failure would occur in less than 3 microseconds or not at all. Thus the minimum flashover alone not only may offer no protection, but may be a definite hazard to the system, since it may result in an outage which would offer no protection in any event.

If the curves in the 3 papers mentioned are intended to illustrate general characteristics of surge tests irrespective of wave shape, then it might be said that the flat part of the curves exist as illustrated. The flat portion may be true for slow waves where flashover occurs on the wave front or at the crest. In that event, the flat part of the curves exist and the short time to flashover does not. Therefore, while the curves may illustrate a general principle, they must be used with care, since the complete curves as illustrated do not represent all possible wave shapes and must be limited when one wave only is considered. A complete family of curves would be necessary to represent relative volt-time curves for all waves.

It is significant that the authors of all 3 papers (excepting the committee reports) in this group, have expressed some unfavorable comment on bushing gaps. Laboratory tests indicate that bushing gaps have several undesirable features, which makes them a hazard rather than a help. The one point in favor of bushing gaps is, that it is possible with these gaps in general to obtain the same flashover for both polarities at minimum voltages. Power arcs frequently whip in any direction and the use of bushing gaps encourages an arc to form near the surface of porcelain where it can do considerable damage. The impulse characteristics of bushing gaps are very similar to rod gaps and, therefore, their usefulness for surge voltages is limited to minimum flashovers with slow waves. They are useless for fast waves, as previously mentioned in the discussion of "flat" curves. They are also useless at the high overvoltages where they are most needed, unless an unusually low gap spacing is adopted. If a parallel rod gap is desirable to protect the bushing, a spacing considerably less than the usually recommended gap spacings for bushings must be adopted if overvoltage protection of the bushing is expected. This low gap spacing is necessary because an overvoltage arc tends to follow a surface, where at minimum voltage an arc may strike clear. This phenomenon is observed also in strings of suspension insulators. For example, in an insulator string equipped with arcing horns, the horns may be so adjusted that the arc will strike clear between the horns at minimum flashover, but unless an unusually low spacing between the arcing electrodes is adopted the arc may cascade the insulators on high overvoltages exactly as though the horns were not present. Bushing gaps and rod gaps are parallel cases to the insulator string.

These gaps adjusted to the so-called test gap spacing, may flashover at minimum impulses, and at the high overvoltages, the arc may follow the surface of a parallel bushing exactly as though the gap were not present.

I should like to ask the authors of the 3 papers, if their experience indicates whether most insulation failures are associated with a single severe surge such as direct strokes or if there are a fair percentage of failures that occur with strokes of lesser magnitude and current, such as traveling waves. Recent publications have shown that a large percentage of direct strokes are above 10,000 amperes, and up to 50,000 amperes. It would seem probable that if many failures are due to surges of low current such as arresters are capable of dissipating, that there must be some breakdowns which occur during surges of low magnitude on systems not equipped with arresters. That is, if progressive deterioration weakens insulation, so that failure becomes imminent, such failures would not necessarily be assoicated with direct strokes. However, if most failures are associated with direct strokes, it would seem that more attention should be given to the higher current and energy surges than to those of lesser magnitude.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): The proper solution of the problem of insulation co-ordination depends upon a knowledge of the flashover or failure characteristics of the apparatus to be protected, as compared with the protective level allowed by the protective devices used. If all apparatus had the same shape volt-time curves of failure or performance, the problem would be relatively simple. Thus, if the volt-time flashover characteristics of the line insulator, bus and switch support, bushing, and the puncture of solid insulation as used in the transformer, were all similar in shape, and if the rod gap or lightning arrester were entirely independent of the effects of wave front and current magnitude, it would be possible to maintain any desired levels without knowledge of what sort of impulses must be considered when lightning strikes the line or station.

Actually, however, although the volt-time curves for the lightning arrester and transformer insulation are similar in shape, the bushing, line and bus insulators, and the rod gap, all have volt-time curves which increase very rapidly as the time to flashover becomes short. This characteristic does no harm, and in fact, is an advantage in a device being protected, but is not a desirable characteristic for a protective device. This is especially true when the frequency of occurrence of any particular wave of lightning front is not known. The variation in the rod-gap spark potential from 60 cycles wet to flashover on a 1,000 kv per microsecond front will be of the order of 6 to 1, while the same ratio for the lightning arrester will not in general be more than 2 to 1, the arrester being unaffected by weather conditions.

These considerations lead to the conclusion that, if close and dependable protection is to be expected, one should make use of the lightning arrester installed close to the transformer, with adequate direct stroke protection over the station and for a short distance out, so that waves of known magnitude and steepness can arrive only through the surge impedance of the line, giving rise to voltages across the arrester which can be predicted reasonably well in advance. This allows one to operate with a known margin between the arrester potential and the tested strength of the transformer.

The ideal arrester protection, which has been long recognized as such, would be to have the arrester potential unaffected by either the rate of voltage rise or the amount of current in the discharge. It is true that considerable progress has been made in this direction in the last few years, which provides more definite protective levels than possible heretofore, and yet for the best results and to maintain dependable margins, a knowledge of the maximum magnitudes of the incoming waves is essential, both as to rate of rise and magnitude of current.

These considerations indicate that the greatest lack of knowledge concerning lightning is in relation to the wave shapes and magnitudes which may result from direct strokes at the point where the stroke occurs. This is especially important in connection with distribution systems where direct stroke protection cannot be readily installed at transformers. Knowledge of such wave shapes is very difficult to secure at reasonable expense, and although some data are available much still remains to be done.

Fortunately, waves which travel over conductors, even relatively short distances, are subject to calculation, and are so modified that an exact knowledge of the original lightning stroke is not necessary. This method is conservative, but until more is known of the wave shapes of lightning and the frequency of occurrence of those wave shapes, it appears to be the safest policy to pursue.

Messrs. Sporn and Gross are to be complimented, particularly on the co-ordination chart, which I am sure will be very useful.

With reference to the Melvin-Pierce paper, what was the ampere rating of the fuses used on the 110-kv system discussed on page 691? With the type of repeator fuse used, how quickly does another fuse become available, and is protection lost in the interval? Multiple strokes involve time intervals as short as 0.0005 seconds and successive discharges may be as far apart in time as 0.5 seconds, which makes the answers to these questions of interest.

J. T. Lusignan, Jr. (Ohio Brass Company, Mansfield, Ohio): All 3 papers on insulation co-ordination or selection of insulation levels bring out quite well the factors involved and the advantages to be gained. Messrs. Sporn and Gross very aptly summarize the advantages when they term them "economy." In other words it is merely a case of saving equipment cost and watching the weakest link of the chain. That is, all equipment should be reasonably high enough so as to have small chance of failing, but none should be abnormally higher than others as this usually involves high costs with no particular gain in the net performance of the system.

All of the papers have to do with choosing protective levels and arranging the equipment above them. The question that probably arises in the minds of most readers is how the individual equipment pieces should be arranged relative to one another. Messrs. Foote and North seem to feel that the only care necessary is that all equipment be above the protective level, making no recommendations as to which should be highest or lowest. Messrs. Sporn and Gross seem to favor having the bus insulation the highest in the station.

Whatever procedure is used, care must be taken not to choose insulation levels on too close hair lines. In this regard I would like to emphasize a few points as to the porcelain members involved, that is the bushings and bus insulators. Besides the atmospheric factors which cause the flashover voltages of such insulation to vary, each of these devices has individual characteristics which affect flashover.

Bushings seem to be the most variable in this respect, probably because they have the more involved electrostatic field. This field is that of a rod and torus, with a mass of solid and/or liquid insulation as a principal dielectric between them. It is this mass of insulation which is supposed to support all applied potentials, any relief from high overvoltages being gained by flashover of the air along the outer porcelain shell. The inside insulation has an appreciable effect upon the outside flux of the air, and therefore the flashover characteristics of the bushing. Since some bushings nowadays are made entirely of porcelain or paper, some of porcelain and oil and some of paper and oil, it can be appreciated that each will have the outside air paths affected differently. Also the temperature and condition of the inside insulation has some affect upon the outside electrostatic field. All of these factors combine to make very difficult the problem of standardizing bushing flashover values within narrow bands. There is also the question of using the flashover values secured in a laboratory on a smooth testing tank, with those which will occur when the bushings are mounted on breaker or transformer tanks having protruding metal parts in different arrangements around the base of the bushings.

The question of standardizing bus insulator flashover values is a little less complicated, since the dimensions, materials, and shapes of many of these insulators are rather well standardized today. However, tolerances must be allowed on each side of the flashover values, established under standard conditions in laboratories, since these insulators are not always mounted alike in stations. In other words, some are base-mounted and some cap-mounted, while others are arranged in double as well as single stacks, and with widely different hardware fittings at the line ends.

In those cases where suspension insulators are used in stations, it must be remembered that the established suspension flashover values are based on simple hanging strings in laboratories, and not the horizontal tension strings, with and without jumpers, as is frequently used in some bus structures.

In all of the above papers the need is recognized for putting the "protective level" above the expected switching surge level. The question that I would like to raise is as to what should constitute the switching surge level. Messrs. Melvin and Pierce introduce new data which I feel should change the idea of many of us as to the proper switching surge level. In their conclusions they state:

"The minimum permissible spill-gap settings, for transmission voltages, without adverse effects on service, are less than those previously considered possible.

[a] The lower limit generally applicable is the equivalent of approximately 3.0 times the normal phase-to-netural voltage, in terms of 60-cycle flashover.

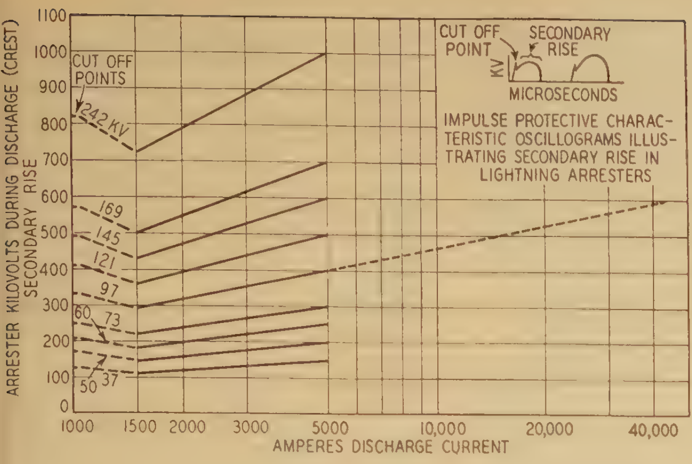

Figure 1. Performance of station-type arresters

Data from table I of paper by Foote and North

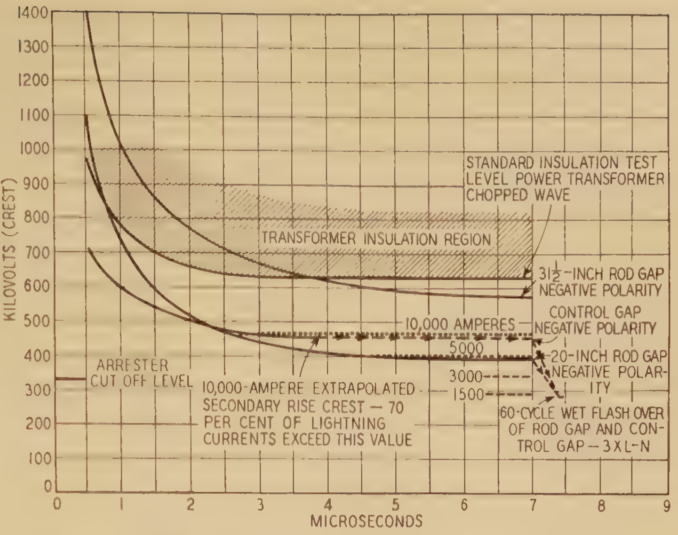

Figure 2. Typical insulation co-ordination showing relative effects of arrester secondary rise and back-up protection of rod gaps and control gap

b. When extremely low protective levels are necessary or desirable and preferably where fused gaps may be applied, the minimum permissible limit may be approximately 2.0 times normal."

Up to now I believe that most of us have felt that a switching surge had the same flashover characteristics as the power frequency wave. Recent work in our laboratory has led us to believe that a switching surge, with its short duration and rapid attenuation, compared to a long 60-cycle wave, might have flashover characteristics higher than the latter and closer to those of impulse surges than originally supposed.

Accordingly, our engineers feel that it is wiser to design a protective device to handle expected lightning surges, overlooking pure 60-cycle overvoltages, on the assumption that the latter is the result of generator overspeeding but not switching. Appreciable data have been gathered showing the crest values of switching surges. We believe that it would be most helpful if more were gathered telling of the wave shapes of switching surges. We feel that this might reveal wave shapes which will permit devices being set appreciably lower than is felt to be safe on the present power frequency basis.

P. M. Ross (Ohio Brass Company, Barberton, Ohio): The operating experience of Messrs. Melvin and Pierce is of valuable assistance in arriving at protective gap levels which are sufficiently low to protect expensive insulation, yet of such magnitude that they can be "lived with" on the system under operating conditions.

The authors mention various switching surge tests conducted to determine the minimum spill-gap settings which are permissible from an outage standpoint. I should like to ask the authors if they can give any information relative to the switching surge wave shapes.

Emphasis has been placed on establishing basic protection levels by means of spill gaps. Such gaps are not subject to deterioration, and remain unchanged by time. There still remains the important problem of determining the time deterioration of major insulation so that a change in basic insulation levels may be adopted to compensate for such reduced levels. I would like to inquire if the experience of the authors of all 3 papers indicates a relative destruction effect of switching surges, induced surges, and direct strokes.

Table I of Messrs. Foote and North's paper illustrates arrester characteristics up to 5,000 amperes. Thus it is shown that for the usual surge or traveling waves arresters are capable of maintaining the surge potential to a safe value.

The authors state in a footnote under table I that station-type arresters can withstand 10,000-ampere crest surge currents. In recent publications statistical data indicate that approximately 70 per cent of stroke crest currents will be in the neighborhood of 26,000 amperes ("The Lightning-Stroke Mechanism of Discharge," McEachron and McMorris, October 1936, *General Electric Review*). The data as presented by the authors in table I have been plotted on a semilogarithmic basis, figure 1. Since the data plotted in this manner are found to lie on a straight line, extrapolation into the regions in which the greater percentage of direct strokes actually obtain seems reasonable. It is thereby found that the secondary rise crest kilovolts across the arrester at 10,000 amperes has risen to 460 kv and to approximately 600 kv at 50,000 amperes (if the arrester will thermally withstand these currents).

It is interesting to consider these figures when they are plotted with typical transformer insulation in view of the authors' statement that "Arresters generally have the following characteristics which are of value in this connection: . . . . (*c*) The performance characteristics are such as to approximate the volt-time characteristics of transformer insulation." In figure 2 is plotted a typical transformer insulation band with a 20-inch negative-impulse rod-gap characteristic (95 per cent lightning strokes on transmission lines are negative polarity), negative-impulse characteristics of a 115-kv control gap set with wet switching surge flashover of 3 times line to neutral voltage and a 97-kv arrester as recommended by the authors for an effectively grounded neutral 3-phase system. The arrester gap breakdown or cut-off point is shown at 330-kv at the ordinate.

The secondary rise crest kilovolts are plotted horizontally. They have been terminated at the 20-inch rod gap, the 60-cycle flashover of which is also 3 times line to neutral voltage. It is to be noted that if surge currents exceed approximately 5,000 amperes the 20-inch back-up gap having a negative minimum flashover of 395 kv will flashover due to the secondary rise across the arrester. Carrying this analysis still farther it is to be seen that the extrapolated value for 10,000 amperes falls at approximately 5 times line to neutral voltage. Currents as high as 50,000 amperes would cause a secondary rise voltage approaching the breakdown of new transformer insulation. I would like to ask the authors if they have any additional data to extend the secondary rise kilovolts crest into the region from 5,000 amperes to 50,000 amperes, also if they have available the total time to crest of the secondary rises for the various discharge currents? Such an analysis as shown in figure 2 indicates that the cut-off point is of minor importance when surge currents of 3,000 amperes and up are encountered as insulation failures are caused by crest voltages, the values of which are determined or permitted by the secondary rise crest of the arrester.

Application of Arresters and the Selection of Insulation Levels

Discussion of a paper by J. H. Foote and J. R. North published in the June 1937 issue, pages 677–82, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937.

H. L. Rorden: See discussion, page 1291.

P. M. Ross: See discussion, this page.

J. T. Lusignan, Jr.: See discussion, page 1292.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): The authors state on page 680 that "The arrester voltage rating must be at least 10 per cent above the calculated maximum sound phase voltage to ground." As we have not followed this practice in Chicago, I should like to discuss it.

The manufacturers state that for modern arresters the 60-cycle breakdown is at least 150 per cent of the arrester rating. This factor alone usually provides a safe margin to justify the use of an arrester rated equal or less than the maximum phase-to-ground voltage during abnormal conditions.

We have been using 3-kv arresters on the 4,000-volt distribution system, which is grounded at the substations through 3/4-ohm reactors. During unusually heavy fault currents, the fuse that normally short-circuits the reactor blows. In general, the ratio Z_0/Z_1 is over 2 when the fuse has blown, and is less than 2 when it has not blown. For faults near the substations our information shows definitely that the maximum line to neutral voltage may reach 3,500 to 3,800 volts, and this condition applies when the fuse across the reactor blows. The fuse blows in about 15 cases a year, or about once every 3 years for each substation. For most faults, the maximum voltage is 3,000 volts or less.

Arresters rated at 3 kv have been used for 25 years on this system with satisfactory results. The rate of arrester failures due to all causes is about 0.3 per cent per year and the rate for the modern type of arrester but a small fraction of this percentage. These failures include, of course, those due to corrosion of the gaps and other deterioration.

For the year 1936, 69 arresters failed in service incidental to lightning. The average distance to these arresters from the substation bus was 7,500 feet. There were also 40 failures of arresters due to unknown causes, and for these cases the average distance from the arresters to the substations was 6,300 feet. The average distance for all arresters on the system from the substation busses was 6,000 feet. The voltages during faults are highest on the line wires nearest substations, and yet this characteristic did not cause a large proportion of the arresters near substations to fail.

Table III of the paper shows a margin of arrester performance in the basic insulation level which includes a circuit gradient of one kv per foot. This value may not be sufficiently high to insure an adequate safety factor under severe conditions. Hodnette and Ludwig reported in their June 1937 paper voltage drops in arrester leads as high as 10 kv per foot in laboratory tests. Lightning investigations on the Chicago distribution system as reported by Halperin and Grosser in the January 1936 issue of Electrical Engineering indicated values of circuit gradient as high as 1.0 to 1.7 kv per foot. In our measurements no cases of transformer failure and only one fuse blowing occurred, although a large number of measurements were made. It appears quite possible that, with lightning conditions severe enough to cause actual equipment damage, higher values of circuit gradient might have been encountered. At least until more definite data are available, particularly for transmission systems, values higher than one kv per foot should in some cases be used in designing and in analyzing equipment performance.

The use of higher gradients reduces or eliminates the selectivity margins given in the paper. Some compensation, however, exists in the 5 per cent or greater differential between the basic impulse level and the transformer bushing flashover. Perhaps the selectivity margin could properly be determined on the basis of actual flashover voltage of the equipment to be protected rather than on the basic impulse insulation level.

These remarks emphasize the authors' recommendation to place arresters as close as possible to transformers or other equipment to be protected.

E. Piepho (Detroit Edison Company, Detroit, Mich.): Foote and North have condensed the great body of available material relating to lightning protection of electrical apparatus, and presented it in a form immediately usable to the operating engineer. Data which they give have passed through the controversial stage and are now widely accepted. Interpretation and use of this material, however, may warrant some comment.

To the section on marginal requirements, the authors might have added a statement concerning the effect of deteriorated lightning arresters, or arresters of earlier manufacture than the more improved types whose performance is shown in table I. Such arresters would give higher voltage drops during discharge than the values shown in the paper. The surge impedance of ground connections is also of great importance since the voltage drop across this impedance adds to the voltage across the arrester during discharge, giving proportionally higher impressed voltages on the protected equipment. For example, on distribution systems ground-connection impedance has so much effect that considerable improvement in protection of transformers has been realized by interconnection at the transformer of the secondary neutral wire and the arrester ground lead.

The selectivity margins shown in table III appear to be comfortable for all voltage classes, yet the operating engineer using these data should bear in mind that these margins can easily be wiped out by any one or more of the marginal requirements having greater weight than assigned by the authors. This has the effect of making each arrester installation almost an individual matter. It also suggests that operating companies using a great number of lightning arresters will find it profitable to undertake a program of testing a certain percentage of new, and all reclaimed, arresters before placing them in service. Furthermore, now that basic insulation levels are being established, operating companies can proceed to test the various kinds of old equipment in service to determine their fitness to operate in their voltage class.

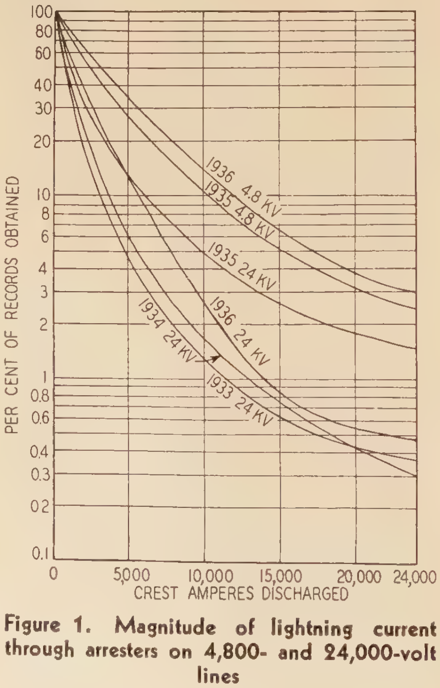

Figure 1. Magnitude of lightning current through arresters on 4,800- and 24,000-volt lines

It is regrettable that the authors were unable to present data on lightning arrester performance beyond 5,000 amperes. The majority of lightning surges passed by arresters appear to be less than 5,000 amperes, nevertheless surges of greater magnitude are not uncommon. Records of surge currents through arresters have been obtained on the Detroit Edison system for several years, using surge recorders in the ground connections of various 24,000-volt arresters, and surge-crest ammeters in the ground leads of arresters on 4,800-volt distribution transformers. H. W. Collins reported the first year results of this investigation on 24,000-volt lines in the May 12, 1934, issue of *Electrical World*. This work has been continued and considerable additional data obtained. The accompanying curves show the per cent discharges at different current values obtained from these records. About 9 per cent of the surges recorded on 24,000-volt lines were over 5,000 amperes, and about 30 per cent were over 5,000 amperes on the 4,800-volt lines. The greater percentage of high current surges on the distribution lines in probably due to greater exposure, since all the 4,800-volt line recorders are located on farm lines, whereas many of the 24,000-volt recorders are in the urban area. These records have also demonstrated that lightning arresters of present manufacture can pass surge currents in excess of 20,000 amperes without damage. Consequently, it seems the time has come for manufacturers to extend the data on voltage across arresters during discharge considerably beyond the present 5,000-ampere limit.

This paper should focus attention of all operating men on co-ordination of equipment insulation which is important because better protection can thereby be secured at less cost. It should also enable manufacturers to standardize somewhat on lightning-arrester characteristics, which should lead to lower costs and consequent broader application of arresters.

Hollis K. Sels (Public Service Electric & Gas Company, Newark, N. J.): Messrs. Foote and North, in their paper on "Application of Arresters and the Selection of Insulation Levels" and Messrs. Sporn and Gross in their paper on "Insulation Co-ordination" bring out valuable comparisons between the protection afforded by lightning arresters and the basic insulation levels of other equipment. While a great deal of information has been gathered on the characteristics of insulated equipment and protective devices, a great deal of information is still needed on the impulse strength of equipment in service and on new equipment being manufactured by those who are not equipped with complete testing facilities or, if equipped, may not have complete information on equipment being built.

The opinion expressed in both these papers seems to be to rate the bus insulation strongest, with bushings, transformer insulation, and lightning arresters following with suitable margin requirements provided in each step. There are 2 major factors which appear to us to need further consideration before they can be standardized on as a general policy. First, while it is theoretically possible to maintain a marginal requirement between steps of only 10 per cent, we believe that in practice it will be impossible to maintain less than 20 per cent between barrier-type insulation level inside transformers and circuit breakers and the protection level because of the deterioration which is bound to take place in insulation and the variation in protective ability of equipment. The company with which I am associated has purchased plenty of equipment which, at the time of purchase was properly co-ordinated, but now, because of its depreciation, is almost as unco-ordinated as if no co-ordination had been made originally. Messrs. Melvin and Pierce have made some allowances for deterioration in their application of spillway gaps. Second, every station design naturally falls into at least 4 levels, that is, line entrance insulation, the disconnecting switch and bus insulation, which are usually the same, the circuit breaker and transformer bushings, which are usually interchangeable but may be gapped differently, and the internal transformer and breaker insulation levels.

Considering the relative cost to repair, and the fact that most busses are sectionalized if not properly protected, it would appear that bus and disconnect supports should not necessarily be the strongest insulation in the station. In our own designs we have tried to adopt the following order of strength:

1. Transformer and circuit-breaker internal insulation.
2. Transformer and circuit-breaker bushings and bus insulation.
3. Co-ordination gap and line insulation.
4. Lightning arresters.

We feel that a minimum margin of 10 per cent between each of these groups, allowing 30 per cent between the transformers and the arrester and 10 per cent between porcelain insulation and the arrester, should give a reasonable degree of protection, both in service and dollars.

We note that Messrs. Foote and North, in setting up their marginal requirements to take care of the distance and potential gradient between the equipment and protective device, have based their calculations on an allowance of a potential gradient of only one kv per foot, which is equivalent to an incoming wave having a 500-kv-per-microsecond front. In our calculations we have used corresponding values of 1.7 kv per foot, which is equivalent to 1,000 kv per microsecond wave front.

While the values assigned in some of our basic assumptions may be debatable, I am presenting this discussion to show that there is considerable need for a further discussion and standardization on the various factors involved. We cannot simply say that here is a basic insulation level which is adequately protected by the protective characteristics of lightning arresters which you can buy today.

L. G. Smith (Consolidated Gas, Electric Light & Power Company of Baltimore, Md.): This paper is an excellent step in the placing of the co-ordination of arresters and station insulation on an arithmetical basis. Until it is possible to accomplish this we are only guessing when lightning arresters are applied. Unfortunately even now we cannot place insulation co-ordination and arrester application on a basis of ready calculation since the data concerning actual lightning discharges are quite meager. However, we do know that

1. Some wave fronts are very steep and apparently the closer the stroke to the substation the steeper the wave front.
2. Stroke currents vary from small values to very high ones and these current values can be expressed on a probability basis.

The data presented by the method followed by the authors are predicated upon wave fronts sufficiently low to permit the arrester gaps to break down before the solid insulation fails and upon surge currents of 5,000 amperes or less. With the present information this is the nearest approach that can be made to an arithmetical solution. However, whether or not this solution represents the majority of the cases is questionable. With lines of the completely shielded or "lightning-proof" type connected to a station, the margin of safety given by the authors can probably be applied with some assurance of being adequate.

However, in the case of stations connected to unshielded lines other factors must be considered. Direct strokes near the station may result in very steep wave fronts being imposed upon the station insulation. As a matter of fact there are no published data giving volt-time characteristics of lightning arrester gaps. If such curves approach those of sphere gaps better assurance of co-ordination is obtained. From published data the probability is that 85 per cent of the strokes will be greater than 5,000 amperes. On unshielded lines the limit of the surge currents carried to the stations will be the insulation level of the lines themselves. However, there will be strokes sufficiently close to the station so that lightning arresters will function before the line insulation has time to flashover, thus probably requiring the arresters to discharge more than 5,000 amperes. Records of lightning arrester and equipment failures justify this point.

In cases where the stroke occurs sufficiently far from the station to permit the line insulation to flashover before imposing a high-voltage surge on the substation the 5,000 amperes assumed by the authors should be ample for practically all operating voltages. However, in order adequately to handle steep-wave-front surges or surges originating close to the station, the ideal arrester is one which has a gap with a volt-time characteristic co-ordinated with the transformer insulation and has an impedance drop for currents up to the point where the arrester element flashes over lower than the impulse strength of the equipment protected.

Therefore, it is believed that, until further data are available, the safest practice in application of lightning arresters is the use of arresters with the lowest possible rating consistent with the dynamic potentials that exist on a given system.

F. J. Vogel (Westinghouse Electric & Manufacturing Company, Sharon, Pa.): The report on "Basic Impulse Insulation Levels" gives a tabulation of voltage classes and impulse insulation levels in terms of crest kilovolts. This basic impulse insulation level is presumed to be the minimum insulation level of any apparatus in a station. It is supposed that transformers should have at least this impulse strength or higher and that protective devices would limit the voltages to a lower value to provide a factor of safety in service.

I note that this is the beginning of a program to standardize the level of all the individual parts of a station. I believe this will lead to satisfactory results if it is recognized that considerable latitude must still be given to the designers of equipment. For example, the level of protective equipment should be the determining value for transformers and other equipment, and there exists at the present time no standardization of these devices. Therefore, the basic impulse insulation level given is purely arbitrary since the foundation, which is the voltage level which can be maintained by protective equipment, is lacking.

There is also a trend toward the use of unit equipment, that is to say transformers with either deion gaps or arresters built into the equipment. Since such devices are self-protecting and are a unit, there is little or no point in setting arbitrarily the impulse levels of any of the parts of such devices. The designer must know the performance of each part and provide sufficient factor of safety so that it is a serviceable piece of equipment. Such equipment might or might not adhere to present standards in so far as the performance of the individual parts is concerned.

These points are also brought out in the paper by Messrs. Foote and North. They point out that it is essential, before designing any structure, to determine the stresses which will be placed upon the structure. In this paper the insulation stresses on transformers and equipment are assumed to be limited by the performance of arresters only, and the limits in the application of arresters are important in considering the insulation co-ordination problem from this angle. The authors have made a very thorough study of the problem, and have arrived at sound conclusions.

Arresters are often applied where, due to overhead ground wires and favorable conditions, it is considered that there is little chance of direct strokes. On the other hand, there are few, if any, locations where it can be stated that there is absolutely no possibility of direct strokes, and many where it is not considered economically possible to guard against direct strokes. Therefore, the performance of arresters when subjected to extremely steep wave fronts and heavy surge currents are the important limits.

In design work, where the stresses are known, it is common to apply a "factor of safety." In the paper, this has been done by the use of a "tolerance factor," and a "selectivity margin." The "gradient factor" is really a factor not dependent on the arrester, but on the application. Let us briefly consider what these factors involve. The "tolerance factor" tells us that the arrester is a manufactured product, and as such is subject to variations when new, and in service. The tolerance and selectivity factors also tell us that there are unknown factors, such as steepness of the front of the surge. The breakdown voltage of any gap is subject to increase when the wave front is steep enough. The question then is, what steepness may be expected, and in turn what will be the voltage and what effect will this voltage have on the insulation? The answer to these questions is not entirely available, and differs for low- and high-voltage classes. It is possibly safe to say that protection, regardless of wave-front steepness, can be guaranteed for the low-voltage classes, but not necessarily so for the high-voltage classes. Further data and discussion of this subject will undoubtedly follow in the next few months.

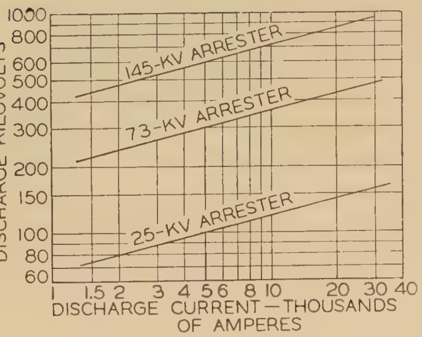

Figure 2. Discharge kilovolt-ampere curve for lightning arresters from table I of paper by Foote and North

The very existence of a distance or gradient factor indicates the necessity of placing the arrester immediately adjacent to the transformer in so far as the transformer only is concerned. The use of a value of one kv per foot may be a fair assumption, but it may be exceeded. In the laboratory, while making steep-wave-front tests on actual apparatus, values 2 or 3 times this high have been seen. There is no guarantee that natural lightning might not occasionally furnish similar results. The practice of locating the protective device, whether gap or arrester immediately adjacent to the transformer appears very desirable from the standpoint of transformer protection.

The question of "surge current" is an important one. Again, surge currents have been assumed at the very nominal value of 5,000 amperes, but there are definite possibilities of currents as high as 10,000 or 15,000 amperes in many cases, to say nothing of the rare cases when there may be from 60,000 to 200,000 amperes. The factors of "thermal ability" to discharge heavy currents, as well as the resultant discharge voltage have not been completely disposed of, as little data are published. A possible extrapolation of the author's data from table I is shown on figure 2 of this discussion for 3 voltage classes. If this extrapolation be correct, the arrester might conceivably cease to protect transformers beyond the following limits: The full wave transformer strengths are 645 kv, 345 kv, and 153 kv for the 138-, 69-, and 25-kv classes, respectively. These voltages will be exceeded when arrester currents in excess of 7,000, 9,000, and 25,000 amperes are encountered. The lack of standardization of arresters is shown by the fact that there are arresters available which will protect these same transformers with discharge currents up to 40,000 amperes or more.

It is interesting to note that the use of the deion gap has been omitted for the low-voltage distribution transformers, in which case there is little or no increase in voltage due to discharge current and no "thermal limitations." This application in certain transformers has had a nearly 100 per cent service record.

The above discussion leads to the same general conclusions as drawn by the authors, and places additional emphasis on the desirability of recommending protective gaps in the station, located as described by the authors, since they provide a limited amount of free insurance against failure of the arrester, and might prevent the failure of a transformer when the surge current is beyond the discharge capacity of the arrester, resulting in too high a discharge voltage.

Insulation Co-ordination

Discussion of a paper by Philip Sporn and I. W. Gross published in the June 1937 issue, pages 715–20, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937.

K. B. McEachron: See discussion, page 1292.

J. T. Lusignan, Jr.: See discussion, page 1292.

P. M. Ross: See discussion, page 1293.

J. H. Foote (Commonwealth & Southern Corporation, Jackson, Mich.): The authors in this paper have presented a most excellent recapitulation of the important considerations involved in insulation co-ordination. They have pointed out that co-ordination has 2 main objectives, (1) protection of service and equipment, (2) economy, and to these we heartily subscribe.

Your attention is particularly called to their "insulation co-ordination chart." This presents, in graph form, for ready use, a vast amount of data pertaining to the insulation strength of apparatus, performance of protective devices, etc. At first, it may appear complicated, but a little study will clearly demonstrate its value in solving insulation co-ordination problems.

L. G. Smith (Consolidated Gas, Electric Light & Power Company of Baltimore, Md.): The authors' classification of the 3 types of overvoltage is quite complete. The first 2 types readily lend themselves either to calculation or to estimation, based upon operating data. However, the third classification, that is overvoltage due to lightning, is still a somewhat indefinite factor and at the same time is the one which is most likely to cause damage to equipment. The practice of the authors' company to install transformers with reduced insulation is a very intriguing one in view of the economic savings resulting. The natural question is whether or not the present-day transformer insulation is too safe from an economic point of view.

In setting a level for transformer insulation, if sufficient information were available, it should be possible to place it on an economic basis, that is, obtaining a balance between capital cost and cost of transformer failures and depreciation. However, to do this it would be necessary to have:

1. Complete information as to probability of strokes of various magnitudes and wave front that could enter stations, in which transformer equipment is installed.

2. Complete volt-time curves of lightning-arrester gaps would be necessary.

3. Volt-ampere characteristics of arresters would be required up to very high surge currents.

4. Volt-time curves of transformer insulation.

5. The effect of repeated voltage strains on transformer insulation, upon the volt-time breakdown characteristics, and upon the characteristics of transformer insulation would be necessary, in order to determine the deteriorating effects of repeated surges.

The lower the margin of safety between the transformer insulation and the voltages to which the lightning arresters will limit the incoming surges, the broader must be the knowledge of the probable types of surges that will be encountered. If the margins are too low, steep wave front surges may damage the transformer insulation before the arrester gap can discharge. Likewise, with low margins, the higher values of surge currents may cause impedance drop in arresters sufficiently high to cause transformer failure.

In reference to the practice cited by the authors of installing the arresters, as close as possible, if not mounted directly on the transformers protected: This is unquestionably an ideal location from the standpoint of lightning protection to the transformers. It is the practice which our company is following. However, it must be remembered that when arresters are installed at the transformers in a large outdoor substation, there may be oil circuit breakers or air-break switches, installed at locations remote from the arresters which might need some supplementary protection. Likewise, air-break switches in incoming lines may be open. As this would constitute a point of reflection, frequent flashovers may occur when such switches are open. With the object of preventing such troubles it has been the practice of our company in 13.2-kv substations to install station-type arresters as close as possible to the transformers, and to install line-type arresters at the terminals of the incoming or outgoing lines. For the protection of such air-break switches, lightning arresters may not be necessary, in that an expulsion protective gap may be used, due to the fact that the volt-time curves of the expulsion protective gap and the post insulator both have about the same shape.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): In connection with the general problem of insulation co-ordination I wish to point out that so far as I am aware the insulation co-ordination movement was started in the transformer subcommittee in 1927, although nothing was published until the 1930 summer convention at Toronto.

This activity was initiated as the result of the failure in August 1926 of some 220-kv transformers having reduced insulation levels (that is, transformers given an induced voltage test of 2.73 times line to neutral voltage) operating on a highly insulated line and without any form of lightning protection. This was the first 220-kv circuit built in the East where lightning was severe and the failure of the transformers brought home the fact that consideration must be given not only to protection against lightning but to the possibility of designs more highly resistant to lightning impulses.

Under item 7 of the minutes of the May 27, 1937, meeting of the AIEE transformer subcommittee, there appears the following heading: "Relation Between Impulse Strength of Transformer Windings, High Voltage Bushings and Line Insulators Near the Transformer Bank." Under this item appears in part the following:

"The question of whether it was best to use the bushing or some external arcing device as a protection to the transformer was discussed and it was the consensus of opinion that it would be poor engineering to use the bushing as a protective device for the windings. It was agreed, therefore, that the committee draw up recommendations on the length of insulators or number of discs which should be used next to the transformer banks of different standard voltages. . ."

The question of co-ordination of transformers was discussed at each subsequent meeting and at the May 9, 1928, meeting the following table for co-ordination was recommended:

System Voltage (Kilovolts)	Maximum Value of Line Insulation Adjacent to Station in Terms of 60-Cycle Root-Mean-Square Dry Flashover Kilovolts
66	250
88	360
110	400
132	450
154	550
187	650
220	750

The 60-cycle flashover given in the above table corresponds to the number of line insulators given in the second column of table I of the report of the transformer subcommittee on "Insulation Strength of Transformers" being presented at this session.

The method of establishing protective levels by means of insulator disks was, of course, quite crude and was soon superseded by the use of the more flexible rod gap or "co-ordination gap." As soon as it was realized that the co-ordination gap did not necessarily co-ordinate, the spacings were increased 10 per cent and its name was changed to "test gap."

This early consideration of transformer insulation co-ordination by the transformer subcommittee stirred up interest in the general problem of co-ordination and, as pointed out in the article on "Basic Impulse Insulation Levels," other committees became interested and this finally led to the formation of the EEI-NEMA joint committee to act upon the broad subject of co-ordination.

It is interesting to note that the test gap spacings given in the EEI-NEMA report and from which the basic impulse kilovolt levels were obtained are the same as those recommended by the transformer subcommittee in 1933. This shows that even though the method of selecting the insulation level was quite crude we arrived at the level eventually selected by the EEI-NEMA committee on a more rational basis; namely, the protective level that is available.

The fact recognized in 1927, as mentioned before, that it would be poor engineering to depend on the transformer bushing as a protective device has been fully justified by later developments. In fact, the latest proposal of expressing the insulation level by kilovolts instead of by test gap eliminates the bushing entirely as the yard stick for even impulse testing of transformers, much less using the bushing as a protective device.

While the industry has been feeling its way for the past 10 years on the problem of co-ordination, making use of the best information available, I think we have finally reached the stage where a logical and practical basis has been reached both for impulse testing of transformers and for protecting transformers in service. This, of course, does not mean that further progress will not be made as many groups are still working along these lines.

Insulation Strength of Transformers

Discussion of a paper by the transformer subcommittee of the AIEE committee on electrical machinery published in the June 1937 issue, pages 749–54, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937.

H. L. Rorden: See discussion, page 1291.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): I wish to comment on 2 points which apparently are not clear in connection with this report. One of the points is the "minimum time to flashover" given in column 8, table II.

The reason why a minimum time to flashover is specified is to prevent the use of a short rod-gap spacing for the chopped wave tests resulting in flashover in, say, 0.5 or 1.0 microsecond, where the impulse strength of insulation is considerably in excess of the strength for longer periods of time to flashover. This increase in strength of insulation is shown in a general way in the volt-time curve for transformer insulation given in figure 1.

The volt-time curve of insulation based on single shots has been fairly well established[*] and the values are as follows:

Time to Breakdown (Microseconds)	Single-Shot Impulse Strength in Per Cent of Full-Wave Strength
3 and longer	100
2	105
1.5	112
1.0	125
0.5	150
0.25	190

The shape of the volt-time curve of insulation based on repeated shots (i.e., 100 shots or more at various time intervals) has not yet been definitely established. Some data are available and tests are now in progress. It is planned to give the results of the tests in a future paper.

The question of how the chopped wave test (110 per cent of the basic level) and the full wave test (95 per cent of the basic level) were arrived at has been asked since this report was published, indicating that their derivation is not clear. As pointed out in the report, the standard bushing level for distribution transformers is 5 per cent above the test gap level which has been in use for some time. Also, the level of power-transformer bushings above 69 kv is approximately 5 per cent above the test gap level. The present impulse test code specifies that in test (*b*) the bushing be flashed over at 5 per cent overvoltage. The maximum impulse voltage applied is, therefore, 10 per cent above the minimum full-wave flashover of the test gap.

Since the basic insulation level given in the EEI-NEMA report corresponds to the minimum full-wave flashover of the test gaps, the chopped-wave test should be 110 per cent of the basic insulation level.

The present test code specifies that the full wave must be not less than 90 per cent of the standard minimum flashover voltage of the standard bushings. Since the basic insulation level or test-gap level is 5 per cent over the standard-bushing level, the new full-wave test should be 95 per cent of the basic level.

To agree with the recommendations made by the subcommittee since this report was written, the 100 kv and 115 kv given in columns 3 and 4 of table II should be changed to 95 kv and 110 kv, respectively. The 110 kv given in column 3 of table III should be changed to 105 kv. The reason for this change is that the EEI-NEMA report has a footnote to table I, page 711 of the June issue of ELECTRICAL ENGINEERING, to the effect that consideration should be given to increasing by approximately 10 per cent, the basic level of 100 kv.

The 100-, 115-, and 110-kv values given in tables II and III, respectively (mentioned above) were based on a basic impulse level of 105 kv instead of 100 kv in anticipating that the basic level would be increased later. It appears rather doubtful now that the 100-kv basic level will be changed.

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[*] Figure 1, page 480, April 1937 issue of ELECTRICAL ENGINEERING, discussion of paper entitled "Dielectric Strength of Transformer Insulation," by P. L. Bellaschi and W. L. Teague.

In connection with the question of gapping bushings on which the report requests comments, now that the impulse test level will soon be expressed in kilovolts and the bushing will no longer be used as a voltmeter during the impulse test, there is no need for gaps on bushings.

However, as a protection to the bushing in those cases where other protective equipment is not provided, a gap may be used in the station to prevent flashover of the bushing and damage to the porcelain by follow current.

Since the volt-time curves of gaps and bushings are similar in shape the spacing of the gap should be at least 10 to 15 per cent below the ungapped-bushing positive-wave flashover, but not low enough to cause undue outages by flashover of the gap. The gap will provide protection to the bushing over quite a wide range of impulse waves. It should be understood, however, that a gap of this spacing will serve only as a protection to the bushing and cannot be depended upon to protect the winding from steep waves because the volt-time curve of insulation is relatively flat.

J. R. North (Commonwealth & Southern Corporation, Jackson, Mich.): This report presents a most excellent summary, both historical and factual, of the insulation strength of transformers and will be highly appreciated by the industry. It will serve not only as a valuable reference report, but will also eliminate confusion in the minds of those who have not been able to follow closely the developments which have taken place during recent years.

Discussion is invited regarding gaps on bushings. In our opinion, based upon experience and analytical studies, the manufacturers' practice of furnishing short rod gaps mounted directly on bushings is very undesirable and should be discontinued for the following reasons:

(*a*) These gaps tend to lead the arc directly along the porcelain and thus they represent a distinct hazard because of the possibility of damage to the porcelain and serious interruption in case of arc-over.

(*b*) These gaps give a false sense of security against lightning surges since the protection is limited to the gap flashover voltage and the volt-time characteristic of the gap may be widely different from that of the insulation to be protected.

(*c*) It is not always realized that care must be taken to insure that the low gap setting required to give some degree of protection does not cause unnecessary service interruptions during switching surges.

We agree, of course, with the thought that suitable lightning protective devices should be installed at stations to protect apparatus from lightning surges. However, these devices should be installed in such a manner as to give proper protection without jeopardizing service or equipment.

An interesting definition of a "directly grounded circuit" appears in the note at the bottom of page 749. We would like to inquire as to the derivation of this statement and how it relates to the values of sequence impedances and sound phase voltages to ground.

Referring to table II, it is believed that the test levels for distribution transformers should correctly be limited to ratings of 69 kv and below.

Basic Impulse Insulation Levels

Discussion of a paper by the EEI-NEMA Joint Committee on System Insulation Co-ordination, published in the June 1937 issue, pages 711–12, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937.

V. M. Montsinger: See discussion, page 1297.

F. J. Vogel: See discussion, page 1295.

J. H. Foote (Commonwealth & Southern Corporation, Jackson, Mich.): This report presents the basic insulation levels expressed in terms of voltage which were agreed upon as the result of a thorough study by the joint EEI-NEMA committee of apparatus performance records, operating conditions, and the characteristics of available lightning protective devices. The next step in the work of the committee is, as stated in the report, "specification of insulation strengths of all classes of equipment in the established insulation levels." It will be noted that a change is necessary in the wording of the scope of the committee, item 2, on page 711.

In presenting table I, "Basic Impulse Insulation Levels," an important note has been omitted. The basic levels are intended to be reference levels. A statement should therefore be included with the table to the effect that apparatus to be suitable for operation in the voltage classifications must have insulation which has an impulse strength at least equal to and presumably greater than the levels as expressed in kilovolts. Insulation strengths in excess of the levels are satisfactory.

In our opinion, the basic insulation level of 100 kv for the 15-kv classification should be raised approximately 10 per cent to a value of 110 kv to line up with the other levels and to properly fit with available lightning protective devices. The basic level of the 34.5-kv classification should also be raised from 190 to 200 kv, to be consistent with the immediately adjacent levels.

The first column of table I is entitled "Maximum Rated Voltage Classification." These named voltage classes are intended chiefly as indexes and the column should better be labeled "Present Standard Voltage Class" or some similar title.

The voltage classifications are those at present generally associated with these values. Basic insulation levels a step higher or lower than shown as associated with the voltage classifications may often be used. For example, where lightning arresters of less than full voltage rating can be utilized on systems having the neutral effectively grounded, insulation levels one step below the basic levels can generally be protected.

Tests on Oil-Impregnated Paper—II

Discussion and author's closure of a paper by Hubert H. Race published in the July 1937 issue, pages 845–9, and presented for oral discussion at the communication and research session of the summer convention, Milwaukee, Wis., June 25, 1937.

Herman Halperin (Commonwealth Edison Company Chicago, Ill.): It was of considerable interest to learn that high power-factor oil does not seem to mean correspondingly high power factor for the impregnated-paper insulation. We have found some increases in the power factor of core oil in the oil-filled cables in service in Chicago. The typical value of power factor of the core oil in new cable was about 2 per cent at 100 degrees centigrade. Since the lines have been in service, it has been found that typical values are about 0.8 and 5 per cent at 60 and 100 degrees centigrade, respectively. In some cases the power factors are higher; for example 15 per cent at 100 degrees centigrade. So far these power factors do not seem to be increasing after the changes occurring in the first few years of service, and there have been no indications of changes in the insulation from what tests have been made on short lines or from temperature measurements on other cable on longer lines.

It is hoped that the author is correct in his deduction that oxidized oil does not appreciably affect the life of samples which are gas-free. In tests on experimental oil-filled 132-kv cables, we have found in one case that changes did not occur until after 3 years of deterioration. Conclusions from this experience as well as from the observations of others, especially the English cable makers on their tests of one year and more, are that unusual phenomena may take a matter of several months or more to develop and give evidence of their presence by means of power-factor tests.

However, the quality of insulation should not be judged on the basis of life on voltage only. Doctor Race found that there is no apparent correlation between life and increase in power factor due to oxidation. In the practical operation of oil-filled cable, such excessive increases in dielectric losses and resultant decreases in carrying capacity can terminate the useful life of the cable without failures occurring.

The conclusion of the author about the longer life of gas-free oil-impregnated paper at one atmosphere as compared to similar cable with gas at pressures up to 200 pounds per square inch is of vital interest in connection with the discussions and tests during the past several years on the various gas-pressure types of cable to operate at 180 or 200 pounds per square inch. The implication of the author's conclusion is that oil-filled cables installed in the regular manner are preferable to these other types of cables.

In interpreting these results, it should be kept in mind, however, that the miniature samples do not represent truly pressure-type cables. In the Hochstadter-Bowden-Vogel pressure cable and the Henley gas-cushion cable, and in some other types, the insulation is impregnated with a heavy, degasified compound, and the insulation is not in direct contact with the gas. In Doctor Race's samples the oil is thin and gas-saturated and is in contact with the gas space. Most of the samples tested under gas pressure were surrounded by a gas space while the degasified samples were surrounded by a large oil volume. It appears that the difference in heat conductivity of the surrounding media might have influenced the test results. It should also be kept in mind that gaseous ionization is depending on both pressure and stress. While 200 pounds per square inch might not be sufficient at the stresses used in the accelerated life tests to prevent ionization, it might be quite sufficient at the lower stresses occurring in normal cable operation.

G. M. L. Sommerman (American Steel & Wire Company, Worcester, Mass.): In connection with the results for specimen 225, for which the saturant was a used oil from an oil-filled cable in service, Doctor Race states that high power factor of oil does not mean correspondingly high power factor of oil-impregnated paper. From figure 2 it is seen that the oil power factor when first measured at 100 degrees centigrade was 0.15, but after heating to 115 degrees centigrade the power factor at 100 degrees centigrade was 0.12. This suggests that part of the high measured power factor of the used oil was due to the presence of moisture or other impurities which could be volatilized, and that the power factor of the oil was much less than that indicated, probably less than 0.05 at 100 degrees centigrade, after the vacuum treatment in the impregnation process. The writer reported (ELECTRICAL ENGINEERING, 1937, page 572) a relationship between power factor of oil and power factor of impregnated paper, but it is necessary to consider the power factors of the vacuum-treated oils in order to obtain this correlation.

The conclusion that high power factor of oil-impregnated paper does not necessarily mean short life as long as temperature equilibrium is maintained confirms a similar conclusion reached by Professor Whitehead (AIEE TRANSACTIONS, 1933, page 1011). Also, in a previous discussion (ELECTRICAL ENGINEERING, 1936, page 1141), the writer pointed out that dielectric loss has no bearing on cable insulation life, unless the insulation loss is comparable with the maximum allowable conductor loss.

The comparison between the life of gas-free, oil-filled cables and the life of compressed gas-filled impregnated cables is dependent on the test conditions, because the life of gas-filled cables is very markedly dependent on the electric stress for stresses in excess of that necessary to initiate gaseous ionization. For the test specimens used by Doctor Race and a test voltage of 22 kv, the stress on a gas film at the conductor surface would be about 1,100 volts per mil if the conductor were smooth; it is actually even greater due to the fact that the conductors are threaded. The breakdown strength of thin films of carbon dioxide or nitrogen under 200 pounds per square inch pressure is about 800 volts per mil. It is therefore indicated that considerable gaseous ionization occurred in testing the specimens which were drained and saturated with compressed gas. If these specimens were prepared with smooth conductors and tested at a voltage of 13 kv (average stress of 200 volts per mil), they probably would last indefinitely.

Hubert H. Race: The first sentence of the second paragraph of Mr. Halperin's discussion is a misstatement of the conclusions drawn from the data presented. While the oil used to impregnate specimen number 202 had high power factor we have no evidence that it was oxidized, and precautions were taken using an evacuated reservoir so that the oil was not in contact with air at any time. Its high power factor was probably caused by asphaltic varnish dissolved from the tape used in making the joint from which it was drawn. The interesting points learned from this specimen are that the power factor of the impregnated paper was much lower than that of the oil alone (see figure 2), and that its stability was good and its life relatively long (150 days at 22 kv and 123 days at 30 kv. See figure 1).

On the other hand, specimens numbers 201 and 202, which were gas free but were impregnated with preoxidized oil, showed less stable life histories and very much shorter life than any other specimens in this group (see figure 1). Also, table VIII shows that upon post-mortem examination, the oil-impregnated paper from specimen number 202, containing preoxidized oil, was much more nonuniform and had from 2 to 10 times the dielectric loss of specimen number 225, containing used oil. It seems to me that these data contradict Mr. Halperin's statement.

I agree with the first and last sentences of the third paragraph of Mr. Halperin's comments—that, from the point of view of the operator, high power factor with its attendant power losses and decrease in current carrying capacity is important. However, for our miniature tests the second sentence of this paragraph is misleading in that as far as is experimentally possible all specimens in the third group were oxygen free, being completely sealed after drying and evacuation to 0.1 micron pressure. Therefore, deterioration during life was not comparable to conditions which might exist in a cable in service if air is accidentally entrapped during installation.

Regarding the last paragraphs of both Mr. Halperin's and Mr. Sommerman's comments, I doubt whether small differences in thermal conductivity had any appreciable effect on life since we have found little difference between tests on gas-free specimens at 60 degrees centigrade and 100 degrees centigrade. Gaseous ionization is certainly a function of both pressure and stresses and it is probable that for any pressure there is a gradient below which little ionization will occur. To say the least, it seems to me that our tests show that the gas-free, oil-filled systems have a higher factor of safety than any gas saturated system up to 200 pounds per square inch pressure, which is the limit of our experimental experience.

Regarding the first paragraph of Mr. Sommerman's comments, I agree that the difference between heating and cooling points in figure 2 was probably caused by the removal of moisture. The point illustrated by this specimen is that the power factor of impregnated paper may be much lower than that of the oil with which it is impregnated. This depends upon the physical properties of the paper and upon the nature of the material in solution or in suspension in the oil causing its high conductivity. In this case I believe the solute was asphaltic varnish, as already mentioned.

The Dielectric Strength of Noninflammable Synthetic Insulating Oils

Discussion and author's closure of a paper by F. M. Clark published in the June 1937 issue, pages 671–6, and presented for oral discussion at the communication and research session of the summer convention, Milwaukee, Wis., June 25, 1937.

E. J. Rutan (Consolidated Edison Company of New York, Inc., New York, N. Y.): It may be desirable to present data from an investigation being carried on as part of committee work in the ASTM on the breakdown voltage test method for synthetic insulating liquids. The present procedure requires 5 breakdowns on each cup filling. For synthetic liquids this may lead to reporting reduced values as seen from the accompanying figure.

The author does not state the details of his test procedure. It might be well if he did so as regards the number of shots and number of fillings in arriving at values of dielectric strength.

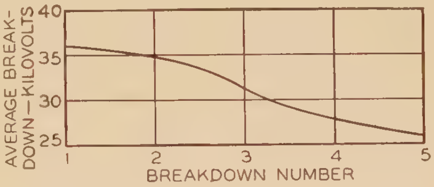

Figure 1. Dielectric-strength tests on 80 fillings of new and used Pyranol, 1934–35

Relative breakdown voltage of each of 5 succeeding breakdowns on the same filling of the test cup

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): While this paper presents very interesting information, it leaves unanswered important questions regarding power factor, thermal properties, and chemical characteristics. It is true that these properties are not within the scope of the paper, but in connection with oil-impregnated paper insulation these properties may be of greater practical importance in some instances than dielectric strength.

It is stated that the Pyranol compounds are mixtures prepared to give the desired physical characteristics for various purposes. No data are presented to show that the results of the one mixture covered in the paper are representative for the various Pyranol compounds, or to show the effect of composition on dielectric strength.

Since the dielectric strength of mineral oil is largely dependent on treatment, the differences in dielectric strength shown between Pyranol and transformer oil might for some types of oil with proper treatment be reduced to practically zero. The author's information, however, does indicate that the Pyranol will retain its dielectric strength better than mineral oil.

The oxidation stability of Pyranol is emphasized, however, on the basis of figure 2. It is known that, for at least mineral oils, dielectric strength is not a reliable criterion of oxidation, and more information on this matter for Pyranol would be of interest. For impregnated-paper insulation, it has been found that the short-time breakdown tests are not a reliable criterion of the performance of the insulation in service. Long-time data would be of interest and value.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): I wish to discuss this paper from the standpoint of using noninflammable synthetic liquid in power transformers.

While up to the present time this synthetic liquid has been used mostly in distribution transformers, 500 kva and less, there is an increasing demand and application in power transformers. Up to the present time the General Electric Company has built a total of approximately 60,000 kva of power transformers using the noninflammable synthetic liquid. Approximately 80,000 kva more are under construction.

One particularly suitable case is where transformers are used in electric cars and locomotives where light weight and small dimensions are essential and noninflammability is important. In the past, locomotive transformers of the air-blast type have been used but they were not entirely successful, as it is difficult to keep dirt and moisture out of the coils. Space limitations prevent using factors of safety high enough to take care of these impurities that get into air-cooled coils, and as a result these transformers have not been immune from failure. Since, for a given spacing, a synthetic liquid (or oil) gives from 3 to 4 times the dielectric strength of air it can readily be appreciated what a noninflammable liquid means in the way of improvement in the design of locomotive transformers. It not only enables one to build a transformer with greatly increased dielectric strength, but makes it possible to maintain this high strength during its entire life. Several such transformers are already in service and the indications are that their use will rapidly increase.

There are also some other cases where a synthetic noninflammable liquid can be used to advantage in power transformers, namely, where the use of an inflammable oil is impractical or forbidden and the voltage is too high for transformers of the air-blast type. In such cases on account of the high cost of the liquid, great pains are taken in the design to reduce the amount of liquid required to a minimum. This minimum liquid space is obtained by the use of a design of tank which reduces the amount of liquid to a minimum. The additional cost of the tank is more than offset by the saving in the amount of the noninflammable liquid.

There are, of course, means of using nonabsorbent high-dielectric-strength materials to displace some of the expensive liquid, provided sufficient clearance is left to allow the necessary flow of oil to carry the heat from the core and coils to the cooling tank surface. Laboratory investigations have shown that the amount of liquid necessary to dissipate the heat is very much less than the amount ordinarily required to fill the transformer.

The broad use of this noninflammable liquid in power transformers for general purposes depends largely upon 2 important factors.

1. Lower cost resulting from improved technique and skill in manufacture of the liquid and from its use in larger quantities.
2. Means for making further reductions in the amount of liquid required in a given transformer.

Both of these developments are being pushed aggressively.

There is no question but that the time is coming when all power transformers will be built with a noninflammable synthetic liquid.

L. J. N. Mothersill (Philco Products, Ltd., Toronto, Ont., Canada): Mr. Clark publishes a comparison of 40 capacitor sections with mineral oil and with chlorinated hydrocarbon impregnant subjected to a stress of 733 volts per mil. What percentage of the conservative working stress is this value in the application of these liquids to (*a*) transformers, (*b*) cable, (*c*) capacitors? In computing probable life of capacitors from accelerated life test at higher than rated voltage it is customary to employ an inverse power relation which has been stated at anywhere from the inverse of the fourth to eighth power of the applied voltage. What exponent is suitable with these liquids and does the author favor direct current or alternating current for such life testing? I would be interested in the drying and impregnation times of the samples.

In a paper published by Jackson, *Proceedings* of the Royal Society, volume 153, the temperature power-factor characteristic of chlorinated diphenyls is reviewed and the power factor shows a decided hump near the solidifying point of the compound and also a decrease in the dielectric constant. Is this general with this type of liquid dielectric? This would appear to affect operation of capacitors in cold climates considerably. It would be of interest in the corona test procedure to know if the foils protrude from the ends of the section (i.e., if they are staggered to give the so-called noninductive winding)? Is the capacitor tissue employed of standard or of special quality and what is the relative value of super calendered and more porous papers? The writer has had some experience with the application of solid chlorinated compounds as capacitor impregnants and would be interested in comparison of the newer liquid impregnants with, say, chlorinated naphthalene. In matching paper and impregnant dielectric constants is it advisable to utilize a paper with high constant but also with accompanying high power factor? These points of discussion apply to cable and to capacitors as well as to transformers in a lesser extent but in the capacitor the stress effect is more easily segregated from temperature effects and that is the reason for approaching the discussion from this angle.

In connection with the chemical stability, the writer has noticed that chlorinated naphthalene gives rise to serious erythema on skin exposed to vapor or solutions of the wax. Is this experienced with the Pyranol type of compound?

E. W. Greenfield (Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.): The dielectric properties of these chlorinated derivatives of cyclic organic hydrocarbons as reported by Mr. Clark are exceedingly interesting. Three characteristics are outstanding, namely, high initial dielectric strength, high chemical stability (as based on dielectric strength measurements), and high dielectric constant.

Although we have occasionally noted dielectric strength of clean dry mineral transformer oil as high as 40 kv (ASTM), there appears to be little doubt from the figures reported by Mr. Clark that the synthetic dielectric liquid possesses a consistently greater electrical strength. It is suggested that the basis of this difference lies in the relatively greater specific gravity and thermal conductivity of the synthetic liquid rather than in a greater ionization potential of the molecule. The conventional dielectric strength tests on oils involve both electric and thermal effects so that impulse dielectric strength testing would be highly desirable in determining the cause of the observed phenomena.

Of the 2 synthetic dielectric liquids studied, Mr. Clark describes a "viscous" type which is indicated as being commercially available for use as a cable saturant. It is assumed from the nature of the data that this synthetic cable saturant is offered as a possible substitute for unsynthesized oils in high-voltage impregnated-paper cables and as such may present certain advantages. Several remarks concerning this use of the new liquids are pertinent.

Table I giving certain physical properties of the viscous synthetic liquid shows a viscosity at 210 degrees Fahrenheit of only 48 seconds (S.U.). This would indicate that the liquid is much less viscous than those saturants normally associated with solid type cable which have viscosities in the neighborhood of 100 to 150 seconds (S.U.) at the same temperature. From the same table I, the pour point of the synthetic liquid is given as +10 degrees centigrade (50 degrees Fahrenheit) which would immediately exclude its use from the field of oil-filled cables, the saturant of which must be limpid at all service temperatures. However, the situation is not as incompatible as at first apparent. From the standpoint of the solid-type cable and its own particular problems, the flow characteristics of the synthetic liquid may be such as to provide a low impregnating viscosity and a high viscosity over the operating temperature of the cable. These features might be desirable, particularly in the so-called "nonmigrating compound" cable applications. However, there is no indication from table I what the flow characteristics are and it is to be hoped that Mr. Clark, in his closure, will present a viscosity-temperature curve of the synthetic liquid under discussion. Data on surface tension and wetting characteristics would also be valuable.

Oxidation stability of cable saturants is normally evaluated on the basis of accelerated aging in the presence of air at high temperature. Of all the dielectric properties studied, dielectric strength is the least sensitive to the chemical changes taking place during aging whereas power factor is perhaps the most sensitive. This is also apparent from figure 1 for transformer-type oils at least over a period of the first 20 days. It is to be regretted that power factor measurements were not made during this same period since any difference in induction phenomena would have been easily apparent.

By increasing the dielectric constant of the saturant, the synthetic-liquid-impregnated papers present a more equitable distribution of stress. The increase in dielectric strength of the laboratory samples when impregnated with the synthetic liquid is probably a result of this more uniform stress distribution in combination with the higher dielectric strength of the saturant. However, it must be pointed out that, in the absence of any description of the test cell or test conditions, no comparisons can be drawn from these results with actual thick-wall cable conditions. In long-life tests of cable samples, dielectric energy loss and gaseous ionization are most important factors. In cases where gaseous ionization may be present, the increased dielectric constant of the saturant may place a heavier stress burden on the vacuous or gas phases, thus lowering the initiating ionizing potential of the entire cable. This, in combination with a high over-all dielectric constant (and generally accompanying high power factor), may place the synthetic liquid saturated cable in a disadvantageous position. Although high dielectric strength of the impregnated paper material as such is desirable, it by no means can serve as a criterion for the quality and stability of the power cable.

F. M. Clark: In considering the characteristics and industrial application of new types of dielectric compounds, the attempt is frequently made to evaluate the new materials from the standpoint of the experience accumulated in applying the older type of compounds which are to be replaced. This frequently leads to confusion and error since many of the ideas developed from experience with the older compounds apply only to such compounds but are often accepted as generalizations of fundamental value. Such an evaluation is to be particularly avoided when the chemical type of compound is so radically changed as in the subject matter of the present paper, wherein the oxidizable hydrocarbon molecules of mineral oil are considered in comparison with the nonoxidizable molecules of chlorinated aromatic hydrocarbons. It is particularly unfortunate that space would not allow me to discuss the dielectric loss characteristics of the compounds presented in this paper. To discuss adequately the dielectric properties of these compounds other than the dielectric strength is also impossible in my closure. I prefer rather to present the data concerning the dielectric loss and dielectric constant characteristics of these materials in a separate paper at some future date.

Mr. Rutan asks whether the dielectric strength data represent single-shot values or the average of a series of tests. All dielectric strength data presented in the paper are the average of a series of 5 tests for each filling of the dielectric-strength test cup. In each case, 3 distinct samples of the dielectric liquid were tested and the total of 15 dielectric test "shots" was averaged. The testing procedure is in accordance with the usual commercial and ASTM practice. In testing the dielectric strength of any liquid carbonization results with each arc-over, the amount of carbonization depending upon the period during which the electric arc is allowed to play. In the test setup used in the present paper, the arc duration is reduced sufficiently in time such that the tendency of a single sample to drop in dielectric strength from the first to the fifth "shot" has been eliminated. With longer time of arc duration, the tendency described by Mr. Rutan is recognized to exist. This drop, however, involves atmospheric conditions of humidity and is most pronounced with increasing water content in the air in contact with the liquid under test.

I appreciate the comments of Mr. V. M. Montsinger. His enthusiasm concerning the commercial possibilities in these liquids strengthens my own. Materials such as described, characterized by a high and permanent dielectric strength, nonoxidizable and of high dielectric constant, possess highly desirable dielectric characteristics.

The 733 volts per mil used in the long-time tests referred to by Mr. Mothersill represent approximately twice the normal working stress of capacitors and a considerably higher ratio to the average working stress of oil-filled cables. In the case of transformers, the usual working stress is considerably lower because of design differences. It is probably possible to predict more reliably the relationship between commercial life and higher-than-rated-voltage short-time life test results under laboratory conditions, using the chlorinated-hydrocarbon-impregnated insulation, than with mineral-oil-treated insulation. This follows because of the chemical stability of the chlorinated hydrocarbon as compared to the susceptibility of mineral oil to change. However, the value of such a relationship, especially for mineral-oil-treated insulation, may well be doubted. Sufficient data are not available in the case of the chlorinated-hydrocarbon-treated insulation to warrant a statement at this time. Furthermore, it is to be observed as stated in the publication that the dielectric failures with the chlorinated-hydrocarbon-treated insulation are so infrequent that no attempt is warranted to establish an empirical relationship between the 733 volts per mil and commercial ratings. The dielectric assemblies referred to were dried at 100–105 degrees centigrade under a pressure of less than 300 microns over a period of 48 hours, after which they were impregnated with the insulating liquid over a period of 24 hours, during which the whole assembly was kept under heat and vacuum after which the assemblies were cooled to room temperature under vacuum while immersed in the treating liquid.

Mr. Mothersill refers to a publication by Jackson in which it is described that the power factor had "a decided hump near the solidifying point." This change is not peculiar for the chlorinated hydrocarbons but occurs with all liquids undergoing a change in state. The actual temperature at which it occurs with mineral oil depends upon the physical characteristics of the oil. We have never found that the changes as described by Jackson are at all effective in determining the dielectric strength and permanency of the chlorinated-hydrocarbon-treated insulation.

All tests for corona formation were made with electrode arrangements in which the edges of the electrodes were practically superimposed. The dielectrics in all cases were of standard commercial quality with no special preparation. It is impossible to compare the dielectric characteristics of chlorinated naphthalene with those of the newer liquid impregnants as requested by Mr. Mothersill. The chlorinated naphthalenes of best dielectric characteristics are high-melting solids limited in their voltage application because of crystalline tendencies. The liquids have the advantage of being able to be operated at higher voltage stresses because of the absence of void formation, the usual accompanying feature of crystalline formation in solids.

Mr. Mothersill requests information concerning the relative toxicity of chlorinated naphthalenes and the chlorinated hydrocarbons described in the paper under discussion. Conclusions concerning this point must be postponed until investigations now in progress have been completed. In the work with which I am familiar, no serious erythema has been encountered.

The present paper describes the dielectric characteristics of blends of chlorinated hydrocarbons and single component mixtures. It has been found that blends in general show the same dielectric-strength characteristics as exhibited by the individual components.

In the dielectric-strength data of the paper, no special treatment has been given either the mineral oil or the chlorinated hydrocarbon aside from the usual commercial preparation. Mr. Halperin's speculation that the differences in dielectric strength between the chlorinated hydrocarbons and the transformer oil mixtures "might be reduced to zero with proper treatment" does not appear to be substantiated in fact.

Figure 2 referred to by Mr. Halperin was in no sense given as an indication that dielectric strength was a criterion of oxidation. Figure 2 was given to demonstrate the ability of the chlorinated hydrocarbon to retain its dielectric strength even under the most severe water-contaminating conditions. It is recognized that low dielectric-strength values are the inevitable result of water contamination in mineral oil.

In answer to many of the comments of Mr. E. W. Greenfield, I refer him to an article entitled "Nonflammable Dielectric Organic Compounds," published in *Industrial and Engineering Chemistry* for June 1937, pages 698–702. The accumulated evidence tends to indicate that the dangers arising from the ionization of trapped gas pockets are materially reduced by the use of chlorinated-hydrocarbon liquids. Whether or not a gas pocket will form in insulation depends upon many factors involving the physical characteristics of the impregnating liquid and the solubility of gases therein. The characteristics of the chlorinated hydrocarbon liquids described in the present paper on the basis of experience seem particularly well adapted to eliminate or reduce the ionization dangers which have been the subject of so much investigation and concern in oil-treated dielectrics.

Properties of Saturants for Paper-Insulated Cables

Discussion and author's closure of a paper by G. M. L. Sommerman published in the May 1937 issue, pages 566–76, and presented for oral discussion at the communication and research session of the summer convention, Milwaukee, Wis., June 25, 1937.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): This paper gives some excellent information on the properties of cable saturants with and without resin added. The data show that the addition of suitable resin to some oils improves the aging properties considerably without deleterious effects on other properties. I was particularly interested in noting that the resultant impregnated-paper insulation had low dielectric losses.

The author's work has in general been carried up to the temperature of 85 degrees centigrade. We have established emergency ratings for cables operating at 4 kv to 33 kv in Chicago based on maximum allowable temperatures ranging from 90 degrees to 105 degrees centigrade, depending on the cable. Although such operation is not expected to occur in more than one day every year or every few years for a given line, yet it seems that the author's work would have been of a little more interest if his temperatures had been carried above 85 degrees centigrade.

Mr. Sommerman found that the stability of naphthenic oils might be improved if better methods of refining them were used. Interest in insulating oils on the part of oil refiners has increased recently and data of this kind should expedite the procurement of better oils. It is indicated that naphthenic oils are more stable to gaseous ionization than paraffinic oils but are less stable to oxidation. In cable insulation of the ordinary or solid type, some void spaces are certain to occur incidental to manufacture and to installation and operation, and stability to gaseous ionization in high-voltage cable is of great importance. The initial losses in cables now being manufactured are low and slight increases due to oxidation, although not desirable, are less important than increases in losses due to ionization because the small amount of available oxygen can be consumed, but the changes due to ionization may be cumulative. At present, it appears, therefore, that long life and best over-all economy will be gained by emphasis on immunity to effects of ionization at the expense, if necessary, of some loss in oxidation stability.

Wm. A. Del Mar (Habirshaw Cable & Wire Corporation, Yonkers, N. Y.): Two types of saturants are now in use in American paper-insulated cables one a naphthenic base oil of tacky consistency and the other a paraffin base oil mixed with rosin.

Cable users naturally wish to know which is the better saturant and why some manufacturers use the pure mineral oil, while others use the rosin blend.

I do not think that the time has come to make a final decision between the 2 types as there is not enough difference to permit a completely logical choice to be made. The prospects of improvement are brighter while the 2 types are both available, as this condition leaves open 2 avenues of development, rather than one.

The case, as I see it, may be summarized as follows:

Arguments for Naphthene-Base Oil

1. It does not leave deposits in the tanks and pipes and thus saves expensive and time-consuming cleanings, which are necessary with rosin blends. However important this may be to the manufacturer, it does not affect the cable user.

2. It gives somewhat lower initial dielectric loss at high temperatures, i.e., above 60 degrees centigrade.

Arguments for Paraffin-Base Oil Blend

1. Ability to maintain a constant initial quality by blending oils from several sources of supply. This is not practicable with the tacky naphthene-base oil.

2. Less susceptibility to oxidation, as shown by Doctor Sommerman.

3. Less migration of saturant, due to greater viscosity.

4. Somewhat greater stability when subjected to electrical discharge in vacuo.

Our research laboratory has made a series of load-cycle life tests to compare cables made with the 2 types of saturants and found little difference, such difference as there was being consistently in favor of the rosin type. This finding is substantiated by data given by Halperin and Betzer, Electrical Engineering, October 1936.

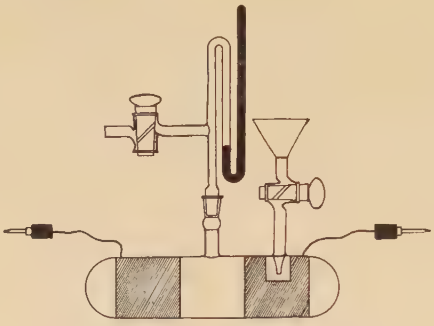

Figure 1. Oil stability tester

The laboratory also made tests of electrical stability in the presence of electrical discharges in vacuo, taking as starting point the work of Z. W. Nederbragt, referred to as number 10 in Doctor Sommerman's bibliography.

This test is based on the well-known fact that insulating oils may give off gas, chiefly hydrogen, under the influence of electric discharge. To determine how various compounds compare with each other in this respect, we have arranged a test set wherein a sample of a given oil is degassed to a constant pressure (1.0 millimeter mercury absolute) in a discharge tube, and then subjected to a glow discharge. The amount of gassing is then measured by the pressure rise in the tube, as indicated by a mercury manometer. The sample is tested for power factor and resistivity before and after exposure to the electrical discharge.

Figure 1 shows the oil stability tester or discharge tube. It is similar to Nederbragt's discharge tube but has added the funnel, stop-cock, and nozzle, shown to the right. These make possible a closer control in the preparation of the oil sample to be tested, it having been found that the rate of gas evolution is greatly affected by the degree of degassification of the oil, as well as by the initial vacuum. The electrodes consist of tin foil wrapped around the outside of tube at each end. Quoting Nederbragt:

"On its way from one tin-foil coating to the other, the current passes through the glass as a displacement current, then as an electron, and ion current through the gas space, and finally again through the glass. A small portion of the current passes through the glass where this is covered with oil and therefore also passes through the oil as a displacement current."

The electrical circuit is shown in figure 2.

A current of slightly under a milliampere is passed through the apparatus with a voltage of about 15,000. We used 60-cycle voltage as being nearer to practical conditions than Nederbragt's 7,500 cycles. The oil becomes agitated and foams, evolving gas and depositing a filmy residue of cable wax.

Typical results are shown by figure 3 in which curve *A* represents a paraffin base oil with 15 per cent rosin. Curve *C* represents the same oil without rosin. Naphthene base oil, as used in solid type cables, gave curves that coincided substantially with curve *C* except that there was less downward tendency at the right-hand side. In other words, the 2 pure oils were substantially equal. The addition of rosin improved the paraffin oil.

Oil-filled-cable oil shows less than half the gas evolution of oil *A*. The oil now used by all the oil-filled-cable makers is the same and has proved to be the best, from the standpoint of gas evolution, of any oil so far tested. There are, however, prospects of improvement.

The different types of failure which occur on load-cycle life test have been puzzling, as have the irregularity of results on apparently identical cables. It is hoped that these oil tests will throw some light on this problem. The apparent irregularities may turn out to be the results of a race between gas evolution and rising power factor. The stability of power factor and resistivity promises to be as significant as gas evolution but we are not yet prepared to make any report on it.

This work is in active progress and it is impossible to predict what will come out of it. We hope, however, to be able to publish more details in the course of a few months.

L. J. Berberich (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): In the last 10 years there has been

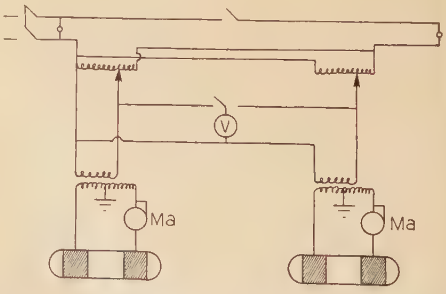

Figure 2. Electrical circuit of oil stability test set

considerable controversy over the use of rosin in cable saturants. The proponents and opponents of rosin are about equally divided. The reason for this division of opinion is perhaps twofold: (1) Whatever investigations of the effects of rosin that have been made were sketchy and did not cover the action of various types of rosins in various types of oils, and (2) the effects of rosin in terms of cable life have not been conclusively shown. Thus, it is encouraging to see Doctor Sommerman's paper, which reports for the first time the results of a careful, wide-range investigation covering various types of oils and rosins. Although the results indicate that a purified rosin compounded with the proper type of oil should result in better cable performance, yet definite proof of this is still lacking.

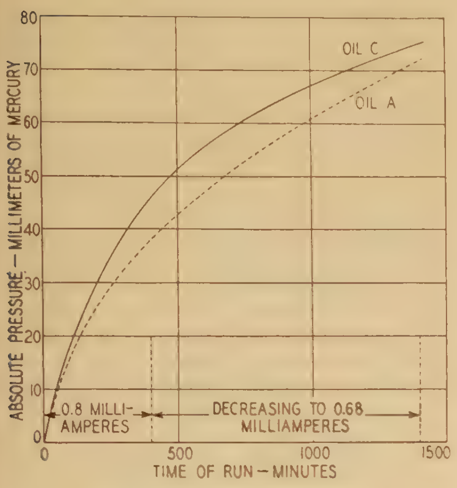

Figure 3. Oil stability tests

Temperature 35 degrees centigrade
Initial pressure = 1.0 millimeter of air

The addition of rosin to cable oils in the past by some manufacturers was encouraged perhaps because it was found that rosin increased the viscosity of the saturant and thus reduced migration, and that it showed some oxidation inhibition. This was done, however, at the expense of increasing the saturant power factor. More recently, however, purified forms of rosin have become available and, as Doctor Sommerman shows, these can be added to mineral oils with little or no increase in saturant power factor

Rosin is believed to be active as an oxidation inhibitor because it itself is easily oxidized, that is, it consumes the oxygen dissolved in the saturant through the phenomenon of antoxidation. Apparently, however, its oxidation products have less effect on the cable power factor than those of mineral oil. The results of Piper, Thomas, and Smith[1] may provide an explanation for this. These investigators have shown that only low molecular weight oxidation products increase the power factor of impregnated paper to a significant extent, apparently because such products are selectively sorbed by the paper. Mineral oil appears to form more low molecular weight oxidation products than rosin does. Rosin itself is a mono-carboxylic acid and because of the peculiar nature of the compound and its high molecular weight, it does not contribute to the saturant power factor when freed of impurities.

Doctor Sommerman also shows that rosin decreases the wax formation for all types of oils studied when they were subjected to gaseous ionization. The writer has found in studying the gas evolution from oils in a low-pressure gaseous discharge that rosin actually increased the gas evolution from low-viscosity-index oils, while for oils of higher viscosity index, the gas evolution was decreased. It was also found that oils of low viscosity index formed considerable quantities of wax and very small amounts of gas and the reverse was true of oils of high viscosity index. This is corroborated by the work of Linder[2] who showed that for pure organic compounds the wax formed decreased as the hydrogen to carbon ratio of the compound increased. In other words, he found that the aromatic type of compound tended to polymerize to a waxy solid with little gas evolution while the paraffins formed little wax and considerable amounts of gas. This does not agree with figure 13 of Doctor Sommerman's paper. Thus it is suggested that in evaluating stability to gaseous ionization, both gas evolution and wax formation should be determined. In the writer's opinion, gas evolution is perhaps more dangerous than wax formation. The wax formed is a fair insulator and results in no serious harm, but the gas may spread throughout the cable and initiate more gaseous ionization which may become cumulative.

In analyzing the oils studied, Doctor Sommerman has listed 3 basic constituents; namely, "paraffinic," "naphthenic," and "residual." Although used in petroleum technology, the term "paraffinic" as related to molecular structure is a misnomer. All oils in the lubricating oil range which have been freed of wax contain no straight chain paraffins. Paraffins having molecular weights equivalent to those of cable oils or even transformer oils, would be solid at room temperature. Petroleum chemists now have evidence that the major portion of the heavier petroleum fractions are polycyclic naphthenes or cycoparaffins with varying lengths and numbers of paraffin side chains. In oils of high viscosity index, the side chains are numerous and long enough to dominate and in the low-viscosity-index oils, the naphthenic nucleus dominates since the side chains are probably small. Oils of very low viscosity index (below 0) contain considerable percentages of aromatic or benzenoid type of hydrocarbons again modified by side chains. This accounts for the steep slope of the viscosity-temperature curve of such oils. The problem of determining the structure of petroleum is exceedingly difficult because the various constituents lie so close to each other in physical and chemical properties that even the most refined methods of separation have failed to result in the isolation of individual compounds.

The data given by Doctor Sommerman should be of assistance to both the refiner and to the cable manufacturer.

REFERENCES

1. J. D. Piper D. E. F. Thomas, and C. C. Smith, *Industrial and Engineering Chemistry*, volume 28, 1936, page 843.

2. E. G. Linder and A. P. Davis, *Jour. Phys. Chem.*, volume 35, 1931, page 3649.

G. M. L. Sommerman: Mr. Halperin raises the question of the relative importance of oxidation stability and stability to gaseous ionization for cable saturants. The importance attached to oxidation stability varies greatly among different cable engineers and it has also fluctuated up and down, during the past 10 years. Only 2 or 3 years ago, the importance attached to oxidation stability was very high as evidenced by the number of researches started, and patents applied for on this subject. Just recently it has dropped to a rather low value. The true value is probably somewhere in between, especially when the cable manufacturing requirements are included in the consideration. Some oils possessing excellent stability to gaseous ionization are so poor in oxidation stability that it is impracticable for a cable manufacturer to use them as straight oils. The addition of 15 per cent improved resin to these oils increases the oxidation stability to a value exceeding that of the oils most stable to oxidation; at the same time the stability to gaseous ionization is increased to a value exceeding that of the oils most stable to gaseous ionization.

It may be noted that the increased oxidation stability imparted by resin additions which was observed in the tests of saturants alone is also evident in aging tests of impregnated paper.

Mr. Halperin states that for reasons involving emergency loadings on cables he is interested in power factor values at temperatures as high as 90 to 105 degrees centigrade (these temperatures are 20 degrees centigrade higher than maximum cable operating temperatures). Data at these higher temperatures were obtained on a number of samples, and these indicate that the power factor-temperature curves in figures 4, 5, and 6 may be extrapolated reliably to 105 degrees centigrade. If a measuring temperature somewhat above 85 degrees centigrade had been employed in the aging tests reported in figures 8 to 11, all the power factors would have been larger in nearly the same proportion, and the same comparisons and conclusions would have been obtained.

The writer is glad to note Mr. Del Mar's confirmatory evidence that the addition of rosin to a paraffin base oil reduces the gas evolution in gaseous ionization tests. The publication of his results on power factor stability in such tests will be awaited with interest.

Relative to the importance of wax formation of saturants exposed to gaseous ionization, mentioned by Doctor Berberich, it may be said that excessive wax formation must be avoided because the wax would interfere with the free radial movement of the saturant in the cable caused by load cycles. This radial movement is necessary for proper operation of cables.

Concerning the form of the wax formation versus viscosity index curve of oils (figure 13), it was recognized in the paper that the wax test results were not conclusive for the 2 oils of lowest viscosity index, and that the wax formation for these oils might actually be higher than that for oils of intermediate viscosity index. For oils in the lower viscosity index range, the behavior would be in accordance with Berberich's suggestion. For oils in the higher viscosity index range, however, the writer observed that the wax formation as well as the gas evolution increased with increasing viscosity index. For these oils, the percentage of aromatic constituents is small in all cases, and the observed behavior may be due to a dependence on the degree of predominance of open chain groups or ring groups in the oil molecules, as suggested in the paper at the beginning of page 575.

Oxidation in Insulating Oil

Discussion and authors' closure of a paper by J. B. Whitehead and F. E. Mauritz published in the April 1937 issue, pages 465–74, and presented for oral discussion at the communication and research session of the summer convention, Milwaukee, Wis., June 25, 1937.

E. J. Rutan (Consolidated Edison Company of New York, Inc., New York, N. Y.): In this paper the authors have attacked a problem which it seems has waited too long for definite data. Particularly interesting are the frequent straight-line relationships which their results develop. Examination of the data on acidity and saponification and its relation to power factor does disclose that the results depend on but a limited range. This is noticeable on figure 11 where one point seems to be used to determine a flattening of the curve. In figures 8 and 10 data are given for acidity number at 0.8 and 1.1 which when computed gives 2 additional points for figure 11 showing the curve to be flat when extended to higher acidity numbers.

In view of the fact that the authors state a change in the ratio of the type of acids is shown by figure 11 it is unfortunate that they did not measure power factor on samples having 0.8 and 1.1 acid number. This would have extended the curves in figures 12 and 13 and made the results more conclusive.

The writer would also like to inquire regarding the reliability of the electrometric acidity determinations. The authors discuss the method in considerable detail giving data on sensitivity and blank determinations but they do not state the limit of accuracy based on several checks of the same oxidation condition. This point is raised because in the ASTM a section has been working for several years on electrometric acidity methods but has been unable to recommend any method as yet as reliable although many methods have been investigated. It would be desirable to discuss this method because this paper will no doubt be referred to by many and the acidity method may be accepted without the necessary investigations.

To this writer the authors' conclusion number 5 does not seem reasonable. Usual experience with dielectric strength measurements on insulating oil in accordance with ASTM methods shows variations between samples of 3 kv which might be 10 per cent of the average. It does not seem reasonable therefore, to attempt to draw a curve through points of less than 1 per cent difference. In my opinion the authors should have plotted the measured values of breakdown voltage giving due consideration to the accuracy of the method. Thus their conclusion would have been that there is no noticeable effect of oxidation on breakdown voltage over the range investigated. It would also have been desirable if data for figure 16 had been carried to the higher acidity numbers. Comparison might be made between figure 16 and the mineral transformer oil results in figure 1 of the paper by F. M. Clark on "The Dielectric Strength of Noninflammable Synthetic Insulating Oils" (ELECTRICAL ENGINEERING, June 1937), which seem also to contradict the authors' conclusion number 5.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): This paper is another stimulating addition to our knowledge of insulation as developed by Whitehead and his assistants.

It is remarkable and interesting to find that in most cases the authors show practically straight-line relations between the electrical and chemical properties. Several other investigators have failed to get such good agreement. It was especially remarkable that the power factor is proportional as well to the acid number as to the saponification number. It would be of interest to learn whether or not this proportionality still holds if the oil is allowed to form soaps. Our data and the data of some others indicate that the various oxidation products are quite different in their effect on the power factor.

Conclusion 2 is based on an inhibition period during which no carbon dioxide is formed and on figure 11. This inhibition period is in accord with some test results of R. W. Dornte (*Industrial and Engineering Chemistry*, volume 28, page 26, January 1936). Probably the high ratio of saponification number to acid number shown in figure 11 at low acid numbers is due to lack of sensitivity of the test for low acid numbers. This is suggested by the data shown in figure 10 indicating zero acid number initially. A slight change in the position of the line in figure 10 could flatten the curve of figure 11 toward a horizontal line.

W. M. Goodhue (Harvard University, Cambridge, Mass.): The paper raised a question in my mind concerning the comparison of oils from different sources. In the paper, a correlation between chemical and electrical properties is given for one oil and, as suggested by the authors, a similar correlation would probably be found if another oil were substituted. But this is not the same as saying that 2 oils from different sources can be directly compared electrically *if the independent variable is not time* but a chemical variable such as oxygen absorbed. The difficulty is that oil is not a chemical individual or even a single series of chemical compounds. The correlation between specific chemical and electrical properties would certainly depend on the proportion of compounds present among the different chemical series, and on the proportion of compounds present within a given series, as well as catalytic impurities. Therefore we have the likelihood of 2 dissimilar oils behaving with stability in reverse order compared to their electrical characteristics if a chemical independent variable such as oxygen absorption is used instead of time.

For example, in equation form, if

$$\text{oxygen absorption} = \alpha_1 t \text{ for oil number 1}$$
$$= \alpha_2 t \text{ for oil number 2}$$

where

$$t = \text{time}$$
$$\text{power factor} = \beta_1 t \text{ for oil number 1}$$
$$= \beta_2 t \text{ for oil number 2}$$

Then, on combining equations,

$$\text{power factor} = \frac{\beta_1}{\alpha_1} \times \text{oxygen absorption, for oil number 1}$$
$$= \frac{\beta_2}{\alpha_2} \times \text{oxygen absorption, for oil number 2}$$

Now with 2 dissimilar oils there is no assurance that β_1/α_1 and β_2/α_2 are in the same order as β_1 and β_2; therefore the change of variable in the power factor from time to oxygen absorption is unsafe, for the purpose of comparing the 2 oils concerning stability, that is in this case the increase of power factor with time.

Therefore I wish to insist that the chemical variables be used only for studying the performance of a single oil throughout its history. When comparing 2 oils, the fundamental variable of time must be used. The excellent curves employing time obtained by the authors themselves show that accuracy can be obtained in an oxidizing apparatus of specified surface areas and other dimensions. This is less empirical than employing a chemical variable instead of time, since with a chemical variable dissimilar oils are not even comparable.

The authors' contributions, however, are valuable, namely (1) a reliable test method for studying electrical properties versus time, under *standardized conditions* of exposure to oxidization and (2) methods of studying the chemical variables. Contribution 1 is suitable for comparing 2 dissimilar oils and contribution 2 is suitable for studying the improvement in manufacture of a single oil. Therefore what has been said in this discussion does not detract in any way from the value of the authors' work and, furthermore, may supplement it when applied to the question of standard testing methods for oils of unspecified origin.

F. M. Clark (General Electric Company, Pittsfield, Mass.): The paper by Whitehead and Mauritz describes a series of oxidation test results obtained with what is described as a "highly refined insulating oil as used in oil-filled cables." Data such as these suffer from the difficulty of interpretation and practical application. However, the continued accumulation of such data may eventually lead to the recognition of worthwhile relationships between the chemistry and the dielectric properties of mineral oils.

There is, however, an underlying thought in the paper which from my own experience demands further consideration because of the attempts which may be made to extend the idea beyond that specifically stated by the authors. This is the thought which is summarized in conclusion number 7.

Experiments in my own laboratory extending over a period of years tend to show that, when on oil of the type used in cables and transformers is oxidized in the manner similar to that described by the authors, substantially the same results are obtained with regard to the linear relationships described. However, there are distinct exceptions to the linear relationship which appear unexpectedly as different oils are investigated or as the oxidation conditions are changed. Furthermore, even when the linear relations obtained by the authors are observed in a variety of oils, they are not of the same character. Although a linear relation between power factor and acid number or saponification may be obtained for 2 oils, the slope angle of the linear relation is rarely the same, indicating a different chemical value for the same power factor. It is because of such variations, which trace back to chemical differences in the oils tested, that but slow progress has been made in attempts to correlate chemical and electrical oil characteristics.

The usual method of estimating the suitability of consecutive shipments of impregnating oil from a definite source of supply is to study the physical and chemical properties of the oil, including an oxidation test and the effect of oxidation on the electrical properties of the oil. In such work, data such as that presented by the authors have been recognized as being of value in the detection of variations from the normal. Too often, however, such laboratory control-of-oil-shipment tests have assumed an importance out of all proportion to their original significance. Instead of being considered as tests to determine continuity of properties from one shipment to the next, they have come to be considered as of fundamental importance. This has led to widespread discussion of oxidation tests of all sorts. While it is true that no oil with abnormally low oxidation resistance would be looked upon favorably by a cable engineer, still the mere fact that an oil may have excellent resistance to oxidation, as measured by tests similar to those of the present paper, is no indication of its suitability for impregnation use. Many interested in the problem believe that just as the lubricating properties of an oil are to be evaluated best by actual test in contact with the bearing metal, so the suitability of an impregnating oil is to be determined best by examination under voltage and in a paper-impregnated assembly. I therefore caution against attempts to extend the conclusions of the authors, especially conclusion number 7, to the extent that such studies are to be interpreted as providing a basis for the determination of the *suitability* of the oil for impregnation use.

Among the oxidation products of mineral oil are acids of low volatility and water. In addition, at the higher test temperatures, oil distillation will occur. I ask whether the authors prevented the removal of such materials by distillation during the oxidation run. One of the major objections to oxidation runs of the present type is the volatilization and loss of those materials of greatest importance in the oxidation studies.

I also request data concerning the iodine value of the oil tested.

The dielectric strength data appear to lose significance because of the dehydration treatment and the removal of oxidation-formed moisture and possibly the more volatile oxidation products before the dielectric test was made.

J. B. Whitehead and **F. E. Mauritz:** The linear relationships which Mr. Clark has found are interesting; there should be some significance to the slope of the power factor versus acid number characteristic. It may be possible to determine the relative proportions of organic acids to other compounds which are capable of dissociating.

We doubt that the withdrawal of the volatile products of oxidation has an important influence on the inherent power factor. Evacuation also removes absorbed oxygen and thus stops the oxidation process. Recently we have found evidence that the oxidation process itself is attended by ionization or dissociation, and that the lowering of power factor on evacuation is due to the cessation of the oxidation process rather than to the removal of oxidation products.

No iodine determinations were made on the oils studied.

In reply to Mr. W. M. Goodhue, obviously it remains to be shown how other oils behave as related to time, and also as to the correlations here studied, and whether there are other correlations with chemical structure. We do emphasize however the striking linear relations we have shown.

In reply to Mr. Herman Halperin, other workers who have thus far reported linear relationships are Clark in this discussion and Sommerman at the National Research Council meeting this past November. Sommerman's paper appears in ELECTRICAL ENGINEERING for May 1937.

It would be interesting to determine the effect of metallic soaps. However, under experimental conditions, it would be difficult to determine the relative contributions of the metal acting as a catalyst or inhibitor for further deterioration and that caused by the metallic salt or soap formed.

The ratios in figure 11 were not determined from data taken from figure 10, as Halperin may believe, but from the individual readings of acid number and saponification number on the oil at a given state of deterioration. This method is, of course, much more accurate.

In reply to E. J. Rutan, the reproducibility of acidity results taken on different oil samples depends almost entirely on the cleanliness of sampling and, more particularly, on the preparation of the titration cell. With due care different samples of the same oil would have a maximum deviation from the average of 0.009 in acid number. This value should be considered as a residual due to impurities introduced and not as directly proportional to the acidity of the oil being measured. It is also imperative to use clear, nonturbid titer and to check its acidity before each oil determination. Great care and labor are necessary in preparing the titration cell, especially for low values of acidity. The agar-agar bridge should be changed after every determination, and for simplicity and speed in routine laboratory measurements we would ask Mr. Rutan to consider also the titration cell developed at Massachusetts Institute of Technology, which involves a glass electrode and which seems much easier to clean.

The oil samples used in the breakdown tests were degassed and dehydrated. Each point on the curves is the average of 15 breakdowns, 5 each on 3 identical samples. While the spread of values was of the same order as the observed average, we feel the latter to be a reliable figure. Slight increases of dielectric strength with increasing acidity in the low range have been reported by others.

Vibration-Measuring Instruments

C. D. Greentree

Dynamic Balancing of Small Gyroscope Rotors

O. E. Esval and C. A. Frische

Discussion of papers published in the June 1937 issue, pages 706–10 and 729–34, and presented for oral discussion at the vibration and balance session of the summer convention, Milwaukee, Wis., June 25, 1937.

P. L. Alger (General Electric Company, Schenectady, N. Y.): These papers give evidence of the rapid progress being made in measuring and describing the various sorts of vibration which give rise to noise and other undesirable effects of machine operation. The need for absolutely smooth operation of motors driving grinding machines and other machine tools, as well as the need for quieter operation of all types of machines, make it important that adequate measuring devices be more generally used, and that methods of describing these measurements be agreed upon by industry as a whole. Difficulties frequently arise now because of customers specifying that motors be furnished with a definitely limited amount of vibration, without saying whether the vibration of the shaft or the bearings is to be measured, and whether the motor is to be mounted on a rigid base, on rubber pads, or in some other way. A revision of the test code for polyphase induction machines has recently been approved, I believe, which includes a provision for measuring the unbalance of small motors in terms of the amplitude of motion of the bearings, when the motor is freely supported on elastic pads. I believe this is a very sensible provision, that will do much toward clarifying understanding on the refinements of design and manufacture necessary to meet industry's requirements.

The next step is to bring into use more adequate instruments for measuring the motion, so that the results obtained by different observers at different times will be in agreement. This evidently requires better instruments than have heretofore been used, and so I believe Mr. Greentree's paper, outlining the requirements for suitable instruments, is an important contribution. As he points out, it may be desirable to measure the velocity of the motion or its acceleration rather than to either measure amplitude directly or to attempt to obtain the amplitude from calculations based on the measured velocity or acceleration of the vibration. If, as is usually the case, the vibration is not sinusoidal in character, there will be no simple relationship between the acceleration, the velocity, and the amplitude of the motion as measured;

and, if, as Mr. Greentree suggests, the measurement of the velocity of the vibration is the most convenient and accurate means of testing, then we ought to be thinking about specifications and industry standards in terms of vibration velocity, rather than amplitude.

The AIEE subcommittee on sound has completed a draft of a test code for apparatus noise measurement, which when published will make available general recommendations on means of measuring noise or any piece of apparatus, based upon the American Standards recently published by the ASA. With the 2 fields of vibration and noise measurement both clarified by these proposed test methods, there appears to be left one further task in this vibration measurement field to be undertaken. That is the question of evaluating the performance of various types of elastic mountings intended to isolate the vibration of a machine from its foundation.

There are a great many varieties of elastic supports now in use and proposed for motors and other machines. Many different types of such supports are, of course, desirable for different applications, so that no general agreement on what type is best can or should be reached. However, it does seem desirable to develop acceptable means of comparing the performance of different types of support by some method, for example, of measuring the vibration transmitted to a foundation with and without the use of an elastic base. Probably it is too early to take the question up in any formal way, but I shall appreciate hearing from any one interested as to the desirability of such measurements of elastic base performance being included in any of the Institute test codes.

Vibration Isolation of Machinery

Discussion of a paper by L. H. Hansel published in the June 1937 issue, pages 735–8, and presented for oral discussion at the vibration and balance session of the summer convention, Milwaukee, Wis., June 25, 1937.

Frederick C. Lindvall (California Institute of Technology, Pasadena): Relating to the paper, "Vibration Isolation of Machinery," by Mr. Hansel, one or 2 points have suggested themselves to me as being worthy of inclusion in this general discussion of vibrations.

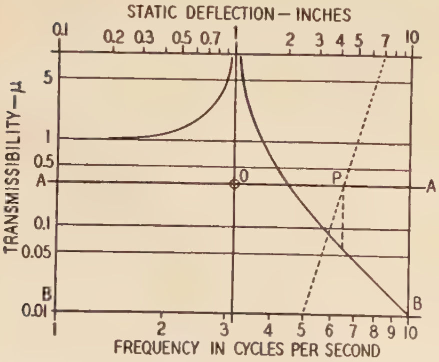

Figure 1. Transmissibility—sinusoidal motion, no damping, one degree of freedom

In the first place, electrical engineers should find the general problem of vibration isolation to be one which is of considerable interest inasmuch as through the electromechanical analogy the problem becomes a simple one of electrical-circuit elements and sinusoidal a-c quantities which lend themselves at once to the symbolic or complex method of solution.

A second point which should be emphasized is the convenient form in which the natural frequency of an elastic system as discussed may be expressed:

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_{st}}}\ \text{*cycles per second}$$

g = gravity acceleration
δ_{st} = static deflection in units of g

Thus it is apparent that if the static deflection of the system is known the natural frequency is also known; from the static deflection, in turn, the spring constant of the elastic support may be deduced when the desirable static deflection has been determined.

A general calculation chart or nomogram which I have found very convenient in vibration studies is one expressing transmissibility of an isolation system directly in terms of the parameters static deflection and frequency of vibration. The mathematical expression on which the chart is based is given by a form similar to equation 1 of Mr. Hansel's paper.

The chart is constructed on log-log paper by laying out the transmissibility curve in terms of the ratio of applied frequency to natural frequency of the system; then through the middle of the chart a horizontal line is drawn which serves as a reference line *A-A*, for entering this transmissibility curve. The horizontal lines *B-B* and *C-C* are suitably scaled in terms of frequency and static deflection, respectively, their positions relative to each other being indicated by the obvious tie that a straight line connecting any particular static deflection on *C-C* with the corresponding resonant frequency on *B-B* should pass through the point *O* on the reference line *A-A*. Then for any desired transmissibility the corresponding abscissa is noted on *A-A* at some point, say *P*. Through *P* and the frequency to be isolated to the extent of the selected transmissibility, a straight edge is laid giving at once the necessary static deflection of the elastic support. This static deflection and the weight at the supports give at once the spring constant. It is, of course, obvious that straight lines through the point *O* relate at once the static deflection with the corresponding resonant frequency. This chart may have a family of resonance curves corresponding to different degrees of damping in the elastic system, the most convenient parameter to be used being the ratio of selected damping to critical damping of the system.

And now a word of caution, or perhaps it should be called "sales resistance," which Mr. Hansel has suggested but which I believe should receive further emphasis. There is no magic in vibration pads or isolation materials. This belief in magic seems, in the minds of many engineers, to be intimately associated with certain materials—one in particular being rubber. In the first place, the term "rubber" is indefinite since we all know the tremendous range of rubber compounds in both elasticity and internal damping, and any rubber or similar material which is to be used as an elastic support should be regarded simply for what it is; namely, a spring which may have either a high or low degree of internal damping. This spring, in turn, is useful as an isolation device to the extent indicated by the transmissibility of the system.

One further point: The engineer employing vibration isolation material should have the 2 basic problems, transmission of vibration and transmission of noise, in mind, because an elastic support of metallic nature which may give an adequately low factor of transmissibility will be capable of transmitting noise to an extent that may be objectionable; whereas some other material, such as felt, or rubber, with the same static deflection will achieve the same desirable transmissibility and minimize noise transmission through elimination of direct metallic connection.

P. L. Alger: See discussion, page 1305.

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* Note: $f = \frac{3.12}{\sqrt{\delta_{st}}}$ cycles/per second

δ_{st} = static deflection in inches

A-C Motor Protection

Discussion and author's closure of a paper by C. W. Kuhn published in the May 1937 issue, pages 589–93, and presented for oral discussion at the general power applications session of the summer convention, Milwaukee, Wis., June 22, 1937.

E. Herzog (U.S. Army Air Corps, Wright Field, Dayton, Ohio): The author claims adequate protection by means of thermal overload relays even in case of longer starting periods. As pointed out in the previous discussion present long-time thermal-overload relays do not offer enough protection in starting high-inertia load. In the starting of blowers where air loading increases rapidly as the blower comes up to speed, the condition becomes most serious. The writer has been able to obtain satisfactory protection only in one way, i.e., by separate protection during the starting and the running periods even with across-line-starting motors. This naturally increases the cost greatly.

C. W. Kuhn: It has not been possible to obtain motor protection with general-purpose thermal-overload relays when starting high-inertia load. Such overload relays must be designed to protect many different classes and designs of a-c motors. Their tripping time must, therefore, be sufficiently short to protect those motors having limited capacity for starting conditions.

The use of special "slow tripping" thermal overloads permits starting high-inertia loads without unnecessary tripping of the overload. Consequently, smaller overload heaters can be used than would be possible with the faster-tripping standard-type thermal overload. These slow-tripping overloads of lower current rating can be made such as to completely protect motors with high-inertia starting load.

Coincidental Electric Drives

Discussion and author's closure of a paper by L. E. Miller published in the May 1937 issue, pages 578–82, and presented for oral discussion at the general power applications session of the summer convention, Milwaukee, Wis., June 22, 1937.

L. M. Nowacki (General Electric Company, Schenectady, N. Y.): Mr. Miller described a very interesting application of a coincidental electric drive, namely, the winding of strip material on a reel. A requisite of the drive is the maintenance of approximately constant tension. The d-c motor is most adaptable for the application. Nevertheless, the question arises, can the same result be obtained with an a-c motor?

Exact coincidence can be obtained with 2 wound-rotor motors used as power Selsyn units or Synchrolocks. The reel drive requires a continually decreasing speed of rotation and an increasing torque. The change in the Selsyn motor speed may then be accomplished by a differential Selsyn unit placed in the rotor circuit between the transmitter and receiver Selsyn, or it may be accomplished by the use of a variable speed transmission interposed between the main drive and the Selsyn generator. As in the case Mr. Miller described, a regulator would be required with the function to control the speed of the differential Selsyn unit or the pulley ratio of the mechanical transmission. If the regulator is to operate on a constant-current principle, it will be necessary to vary the input voltage to the Selsyn units in order to maintain constant rotor current with increasing torque.

The application of an a-c motor to the coincidental reel drive does not appear impossible. A suitable regulator, if developed may provide an a-c drive as flexible as the d-c drive described by Mr. Miller.

E. Herzog (U.S. Army Air Corps, Wright Field, Dayton, Ohio): The double-winding motor controlling the field rheostat appears to be the heart of the entire control scheme proposed. A torque motor with spring restraint and a single winding should be able to accomplish the same purpose. The author states that the double winding was used to give the characteristics of an infinitely long spring. A more detailed explanation of this point would be welcome to the writer.

L. E. Miller: Mr. Nowacki has suggested a very intriguing problem in the use of a-c with Selsyns or Synchrolocks driving a reel on which material is being wound. There is considerable question as to whether the amount of apparatus required could be reduced materially in using a-c as suggested. Like many problems of this sort considerable thought, experimentation, and actual trial will be necessary before any definite conclusions can be drawn on the subject.

Mr. Herzog has brought up the point that a spring might be used instead of the spring or reference winding on the control motor. This is absolutely correct only in case a spring of infinite length is used and deals with finite torque.

Otherwise a greater torque is required of the torque winding as the reeled material approaches full diameter and slowest speed. This greater torque requires a larger current in the torque winding and therefore in the armature of the motor driving the reel and this in turn gives a greater pull or tension on the material as the diameter of the reeled material increases. In other words a spring could be used only where the conditions were such that a varying tension could be permitted on the material.

In closing, attention should be called to 3 errors which occurred on page 581 of the paper. First, in figure 4 the rheostat in series with the spring winding should be marked 1 instead of 2; second, in figure 4 the legend *D* should be "regulator field contactor"; third, the first sentence of the second paragraph starting on page 581 should start, "the torque winding *T* of the regulator. . . " instead of "the torque winding *R* of the regulator. . . ."

New Oil-Filled Cable Lines in Chicago

Discussion and authors' closure of a paper by Herman Halperin and G. B. Shanklin published in the June 1937 issue, pages 739–48, and presented for oral discussion at the power transmission session of the summer convention, Milwaukee, Wis., June 22, 1937.

Wm. A. Del Mar (Habirshaw Cable & Wire Corporation, Yonkers, N. Y.): In summarizing the paper by Halperin and Shanklin, the former said that there is nothing mysterious about the installation and operation of oil-filled cable; that it can be handled without difficulty by crews trained in work on cables of the solid type. This inspires me to add that there is nothing mysterious about its manufacture. On the contrary, the manufacturing processes are based on better-understood principles than in the case of solid-type cables. The mobility of the oil makes it possible to ascertain the condition of the oil and the perfection of impregnation along the entire length by simple tests made at the ends, not only when new, but at all times in its life. This is not the case with solid-type cable, the condition of which must at all times be taken more or less on faith.

The perfect electrical record of oil-filled cables has enabled manufacturers' engineers to devote their attention to improving economy, whereas in the case of solid-type cable the main effort is directed toward improving reliability. This drive toward economy has resulted in simplified accessories, thinner insulation, and cheaper lead, as described in the paper.

Herman Halperin: It is gratifying to have a public statement from a manufacturer of the efforts of manufacturers to improve the economy of oil-filled cable.

Although considerable effort has been and still is being directed toward improving the reliability of the solid type of cable, considerable effort has been and still is being given toward improving the economy of such cables.

The essential consideration from the standpoint of a utility engineer is over-all economy, that is, total annual charges per kilovolt-ampere of carrying capacity. In some cases special considerations, such as limitations of diameters of existing ducts or limitations of the personnel of a utility, swing a decision to one or the other type of cable, although the initial installed cost of the cable and accessories is somewhat higher than would have been the case if a type of cable were used other than the type actually selected.

Impulse Operation of Magnetic Contactors

Discussion and author's closure of a paper by Carroll Stansbury published in the May 1937 issue, pages 583–8, and presented for oral discussion at the general power applications session of the summer convention, Milwaukee, Wis., June 22, 1937.

E. Herzog (U.S. Army Air Corps, Wright Field, Dayton, Ohio): The author describes a very ingenious solution for the short time operation of magnetic contactors. The process is clearly designed to be used in the resistance welding of nonferrous metals where now vacuum-tube control is used. The writer having used these in the past would like to have the author furnish more detailed information on several points. What is the accuracy of timing of the new process? How is a change in timing accomplished? Are there any chance variations of large amounts as the operation is repeated? How would the life of the contactor compare with the life of the tubes in the 2 types of equipment? A rough comparison of first cost and maintenance of the 2 types would be of interest.

Carroll Stansbury: The questions asked by Mr. Herzog are the essential ones which must be satisfactorily answered before control of the type described can be seriously considered for short-time welding of nonferrous metals.

ACCURACY

It will be clear from the paper that the major causes of inaccuracy in contactor control are eliminated by the method. Reference to figure 3 will show that anything which affects the speed of motion of the magnet armature at the instant the contacts touch will affect the closed period slightly by causing the motion to be in accordance with a different one of the family of curves. About the only thing which may cause this type of variation in practice to any serious extent is a considerable variation in line voltage. On the other hand, a reasonably constant line voltage is an essential requirement for this type of welding to obtain constant energy input into the weld for a given welding period.

There remains the question of variation in the number of cycles passed by the contactor due to possible variation in the arc on the contacts. We have found it possible on a number of practical installations to control this factor so that such arcing as is obtained is quite uniform and that there is no perceptible variation in the welding results throughout a large number of operations. One particular installation, which is operating at $^1/_2$ cycle on current on the order of 250 amperes at 440 volts, has continued to give welds with this timing over a period of several months without perceptible variation. Only occasional phase adjustment is necessary.

TIME ADJUSTMENT

This question is covered under the above heading in the paper. The amount of capacity in circuit is varied by cutting in or out individual electrolytic capacitors in parallel.

CHANCE VARIATIONS OF LARGE AMOUNT

Neither our laboratory nor field experience with this control indicates occurrences of this sort.

CONTACTOR LIFE

As brought out in the paper, when operating on the true impulse basis in which the magnet does not seal, the conditions normally producing magnet wear are absent and a contactor should last for several years even on frequent operation. The magnet life on contactors of the best grade used in resistance welding work where the contactors seal in operation is on the order of 20 million operations. This life should be multiplied many fold when the magnet does not seal. So far no contactor operated by the impulse method has shown appreciable wear except on the contacts. It will be evident that with the arcing held to a minimum by this method of control the contact life should also be increased many fold and our experience indicates that this is the case.

FIRST COST AND MAINTENANCE

It is difficult to give any data regarding first cost of control of this type relative to control of all-electronic type which would be applicable throughout the full range of ratings which might be required. Actually, most of this controller is electronic and it is probably correct to say that the essential difference is that the 2 power tubes are replaced by contactors. Taking the material involved apart from the power tubes or the contactors as roughly about the same, the question really reduces to a comparison of first cost and maintenance of the contactor versus the power tubes. It has been pointed out above that the contactor should last indefinitely with only occasional replacement of contacts, whereas it is the writer's understanding that the power tubes either have to be replaced periodically or are of the continuously-pumped variety which doubtless involve maintenance of the pumps and associated parts.

Actually, the necessary apparatus associated with the contactor in this type of control appears to be somewhat simpler than that associated with the power tubes in those types of all-electronic control with which the writer is familiar. The present form represents a considerable simplification in comparison with the earlier forms of this control, and it is probable that further developments will bring out the possibility of still further simplification.

System Recovery Voltage Determination by Analytical and A-C Calculating Board Methods

Discussion and authors' closure of a paper by R. D. Evans and A. C. Monteith published in the June 1937 issue, pages 695–705, and presented for oral discussion at the power transmission session of the summer convention, Milwaukee, Wis., June 22, 1937.

W. F. Skeats (General Electric Company, Philadelphia, Pa.): The authors have developed 2 major ideas which will undoubtedly be of value in certain fields in the determination of recovery rates. The introduction of symmetrical components is helpful particularly in the calculation of the recovery characteristic of line-to-ground faults and the use of the calculating board promises a reduction of labor especially in the determination of the slower voltage-recovery curves.

In the introductory discussion, the suggestion is made that recovery characteristics be specified by stating both co-ordinates of one point on the curve instead of merely the slope of the steepest tangent passing through the origin. This information is somewhat more specific; however, the authors themselves point out that one point on the curve may be the important one for one interrupting device and a different point for some other device, so that there may often be some question as to which point to specify. To give all the information, the complete curve should of course be shown. Comparison of curves of different shape is likely to involve uncertainties, however, and to overcome this, the suggestion was made 2 or 3 years ago that the basis of comparison be the rate of rise based only on points on the recovery curve whose magnitude is at least 80 per cent of the normal voltage peak, with special consideration given to lower points on the curve which correspond to a higher rate where it is a question of breaker application rather than evaluation of test results.

There are one or 2 points with reference to the use of symmetrical components which will bear comment.

1. The paper states that the method of connecting the phase-sequence networks for recovery rate determination is the same as for the steady-state condition, with the apparent implication, supported by the example given in the case of the double-line-to-ground fault, that the proper connection is the same as that used to determine the current flowing in the case under consideration. Except for line-to-line or line-to-ground faults, this is incorrect for, while the calculation of steady-state current correctly ignores the interval during which less than the full number of phases are faulted, this interval must be considered in determining voltage recovery phenomena. The arrangement to be used for the first phase to clear of a double-line-to-ground fault is therefore that of the impedance encountered by current passing from one terminal of the 3-phase circuit to ground with a second terminal grounded.

2. Barring asymmetrical circuit conditions apart from the fault, the difference between positive- and negative-phase-sequence impedances exists only in rotating machinery and arises from the fact that while one is associated with a flux path that is stationary with respect to the field structure and therefore does not change throughout the cycles, the other is associated with a flux path which rotates with respect to the field structure and may therefore be subject to cyclic variation. In the course of 500 microseconds the motion of the rotor has negligible effect, so that the use of the same value for positive- and negative-phase-sequence impedances is justified. It is suggested, however, that inasmuch as with the current zero occurring at the crest of the voltage wave, the flux path in the rotor is that of the quadrature axis, the quadrature-axis subtransient reactance be used in place of the negative-phase-sequence reactance. This is of importance particularly in laminated-rotor machines without amortisseur windings.

3. For very careful calculations it is occasionally desirable to take into account the fact that the capacitance is not the same for the 3 phases in the interval between clearings on the various poles of the breaker. This greatly increases the difficulty of the solution by symmetrical components and is often easily taken care of in the "single phase" solution, so that in such cases the single-phase solution becomes the simpler even neglecting the labor of changing the constants over from one system to the other.

With reference to the use of the calculating board, I should like to make the following comments.

1. From the standpoint of circuit breaker performance, the cases in which recovery rate should be investigated are in general those in which the capacitance on the one hand is small and can usually be lumped so as to make the calculation relatively simple, but on the other hand consists of a number of minor elements so that considerable labor and possibility of error are involved in determining it. Thus the use of a calculating board eliminates only a minor part of the total labor.

2. Moreover, unless the calculating board is specially designed and very carefully used, it seems likely that it would introduce stray capacitances sufficient to cause appreciable errors in such cases.

Except in cases where a recorded recovery transient is to be compared with a calculated curve for the purpose of analyzing effects introduced by the breaker, great precision is not required for circuit-breaker work, errors up to 25 per cent being tolerable. This being the case, the determination is not so much a precise calculation of complex circuits, as a matter of good judgment in making simplifying assumptions. It would seem, therefore, that perhaps the greatest use of the calculating board, from the standpoint of circuit-breaker application, may be in the investigation of such assumptions and the formulation of rules for making them sound.

In applications of expulsion protective gaps, on the other hand, the calculating board offers an appreciable saving in effort.

H. P. St. Clair (American Gas & Electric Company, New York, N. Y.): In this paper Messrs. Evans and Monteith have presented an interesting and helpful contribution to the literature on voltage-recovery transients, and the proposed method of direct measurements of transients by means of the a-c calculating board may prove to be very useful. For instance, if it is necessary to determine the recovery-voltage characteristics in connection with the operation of flashover tubes at various points on the transmission network, this method would simplify the problem since determination by analytical methods would become extremely complicated.

However, it should be pointed out that regardless of the difficulty of calculating recovery transients at various points on transmission lines, the actual severity of such transients is inherently much less than the severity of recovery transients obtainable on station busses with no transmission lines connected and with only the capacitance-to-ground of the busses, transformers, or generators themselves. Therefore, in determining the severity of recovery voltage transients which must be handled by circuit breakers, we are concerned chiefly with the station type of circuit, where it is possible to encounter the higher voltage-recovery rates.

For this general type of problem, therefore, it is questioned whether the authors' proposed method will actually provide much help.

In the first place, these circuits giving the most severe recovery transients are usually of a fairly simple nature and can be calculated fairly readily after the constants are known. In such cases where we are interested primarily in the worst condition which the given circuit can offer, the most difficult part of the problem is an accurate determination of the small values of capacitance involved in the station bus and in the transformer or generator windings. The authors have referred briefly to this problem in the paper, and it is obvious that the a-c calculating board cannot be of any assistance in connection with this part of the problem. It is doubtful, therefore, whether its use in such cases would be justified.

In the second place, it is doubtful whether the equipment described by the authors would be adequate to record very severe voltage-recovery transients since such transients frequently involve a time duration of only a fractional part of those which the authors discuss. All of the typical records reproduced by the authors both from analytical determinations as well as from direct measurements are of comparatively slow transients which would not be of particular interest in the circuit-breaker problem. For example, in figure 22 the recovery transient for a line-to-ground fault on a 132 kv line is shown with approximately 130 volts per microsecond. All of the other transients shown are more or less of this order. Actually, circuit breakers have been called upon to handle recovery rates at least as high as 4,000 or 5,000 volts per microsecond, and for such transients, it is believed that the rotating type of recording device as used by the authors could not possibly be operated at sufficient speed to give the necessary time scale.

As stated above, the most difficult part of the problem in connection with extremely high rates of recovery voltage is the determination of small values of capacitances involved in more or less simple setups. For this problem it is likely that a greater contribution would be some device either for directly measuring transients in the circuit itself or of measuring the capacitance of the circuit directly. For example, the high-frequency generator or oscillator may be used for determining the natural frequency of the circuit and thereby arriving at the capacitance since the inductances involved are generally known.

The authors are to be congratulated, however, for having worked out a very interesting application of the a-c calculating board and one that may prove of great value in its field.

J. R. North (Commonwealth & Southern Corporation, Jackson, Mich.): Experiences which we have had with arc-interrupting devices have time and again brought to our attention the need for more information and data concerning recovery voltage. The methods of analysis described in this paper by Messrs. Evans and Monteith will be of considerable assistance to power system engineers in applying interrupting equipment.

The question of recovery voltage is important not only in the application of circuit breakers, but in all arc-interrupting devices such as fuses, lightning arresters, and protector tubes which may be located at stations or out on lines. Also, the problem is not confined to fault conditions. For example, circuit breakers used for normal switching of synchronous condensers, and line charging reactors, have at times shown considerable distress due to a high rate of rise of recovery voltage. Certain lightning arrester troubles have also been encountered which could be traced to rapid recovery voltage of the system.

Fuses usually clear faults in a relatively short time. The curves shown in figure 26 show that the voltage rise during the first 200 microseconds is much steeper for a fault having a duration of one-half cycle than for a fault of one cycle duration. This would seem to indicate that fuse and protector tube applications require particular attention from the standpoint of recovery voltage.

The reduction of a power system of any size to a simple equivalent network system such as is shown in figure 11 involves considerable work. It would be desirable to have a more detailed explanation as to just how this is accomplished, and with particular regard to obtaining the proper values of equivalent system constants to give the correct values for both normal system frequency and for the natural frequency of the system. It would also be interesting to know how this is taken care of on the a-c calculating board, which is designed for 440 cycle operation.

In the caption for figure 27, it is believed that reference should be made to figure 18 rather than figure 19.

The check between the values obtained by the authors using the analytical method and the a-c calculating board with the field tests is indeed interesting. With more test data available, it would appear that the burdensome analytical studies could be confined to special problems involving only a few elements of a system. It is, therefore, urged that measurements be made of recovery voltage whenever the opportunity presents itself in connection with other system tests. These data will facilitate the application of the methods outlined in the paper to general system studies.

S. B. Crary (General Electric Company Schenectady, N. Y.): The authors are to be congratulated for the presentation of a paper which should prove to be of real benefit in studying the effect of various factors on the recovery voltage characteristics.

In using a minature system or model, it is well to view rather critically the assumptions required in order that the model may be used to predict or explain actual system performance. Unfortunately, the most important cases of arc suppression which result in extreme or high recovery voltage are the ones which do not permit of easy representation by a miniature setup. As shown by the authors, high peak values of recovery voltage may be obtained when the current is interrupted off of normal current zero. The amount and manner in which the circuit is interrupted off normal current zero is a function both of the actual arc characteristic of the interrupting device itself and the circuit to which it is connected. For those cases when the arc characteristic is not influenced appreciably by the connected electrical circuit and the characteristics of the interruptor are known, then a device can be made which will duplicate the performance of the actual device. However, for those cases when the interruption phenomena are dependent upon the electrical circuit as well as the interruptor, it becomes exceedingly difficult to build a model which will duplicate actual performance, this case may well be most easily obtained by test of the actual circuit and interruptor.

Another source of high recovery voltage, as shown in the paper "Circuit Breaker Recovery Voltages" by R. H. Park and W. F. Skeats (AIEE TRANSACTIONS, March 1931, pages 204–239), is that due to the saliency of rotating machines, which cannot be easily reproduced in a static setup.

E. M. Hunter (General Electric Company, Schenectady, N. Y.): Messrs. Evans and Monteith have given a very interesting discussion on using the a-c calculating board for estimating system recovery voltages. The procedure which they describe should be very useful to those interested in making a large number of independent recovery voltage calculations on a system.

Interest in recovery voltages centers mainly around the application of oil circuit breakers and expulsion protective gaps to different electrical systems. In modern oil-circuit-breaker applications only the very fast recovery rates of the order of several thousand volts per microsecond need to be considered. These very fast recovery rates usually result from circuits which contain only small amounts of capacitance, such as is found, for example, in transformers and bus work. It is often difficult to reproduce a miniature of this type of circuit and the authors' comments on the suitability of their a-c board for studying these fast transients would be of considerable interest.

The recovery voltages associated with the application of expulsion protective gaps usually are not in excess of several hundred volts per microsecond and accordingly, are of a much lower rate than those encountered in oil-circuit-breaker applications. Usually the mathematics governing the circuits to be analyzed are not too involved, and the recovery voltages can be calculated provided the system constants are known. The biggest obstacle in making any analysis of recovery rates today is the determination of the system constants. A big step toward the solution of the recovery rate problem came with the development of a practical 3-element cathode-ray oscillograph, such as is described in Messrs. Rudge and Wade's paper on "Expulsion Protective Gaps" presented at this convention. With this measuring instrument it is now possible to make field tests and actually determine the recovery rates. With system constants unpredictable, there is a need for more field tests. Once system constants are known, the a-c calculating board will be a useful tool for extending the study of system recovery voltages.

L. R. Ludwig (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The problem of a-c circuit interruption has long been a very important one, both as far as circuit breakers of high interrupting capacity and smaller apparatus are concerned. However, even until 1928, the notions of the phenomena involved in a-c interruption were vague and incomplete. Comparatively recent papers on the subject glibly discuss the "quenching" effect of oil on an arc, and bemoan the necessity of interrupting a circuit by means of a "burning" arc at all.

In 1923, Doctor Slepian began to visualize the true physics of a-c circuit opening, as a result of research with grids and a vacuum arc. By 1925 his "deion" ideas were formulated, and in 1928 in Denver, he presented a paper entitled "Extinction of an A-C Arc" which for the first time called attention to the facts that the arc space between the separated electrodes of a breaker had to deionize before any appreciable voltage could be applied without restriking, that the time available for this deionization was a function of the circuit, and that interruption depended on the relative progress of deionization and voltage recovery.

This paper, mildly discussed at the time, has become the source-book from which our present accepted knowledge has been derived. As appreciation of Doctor Slepian's work grew, there was a rush to the laboratory to test circuit interruptions under actual system voltage recovery conditions. But what were these actual conditions? How to set the laboratory was the problem. The theory was clear enough, but determination of time to crest and recovery voltage under operating conditions was not simple.

The circuits were analyzed mathematically, but several approximations were needed. For several years there has been no completely practical and simple method for determining voltage recoveries.

Now Mr. Evans and Mr. Monteith have devised a tool for the determination of recovery voltage which is accurate, practical, and complete. Their idea of using the calculating board for this purpose is simple, but considerable ingenuity was required in carrying it out. For example, their use of repeated faults in order to get oscillographic records is a clever means of surmounting a mean obstacle.

The methods they have described are simple, check beautifully with field tests as well as calculation, and permit the study in the laboratory of field conditions which cannot be satisfactorily resolved by mathematics alone. We have been given a new yardstick for gauging circuit-interrupter requirements, and the added certainty of testing will prove beneficial to the development and application of breakers and deion protector tubes particularly.

An excellent example of the utility of the Evans-Monteith method is illustrated in their figure 3. It has often been customary in dealing with recovery voltages to speak only of the rate of rise of voltage, and its crest value. Such a description of the facts lacks generality; it is applicable only when testing a device having a recovery curve similar to *D* in the figure. Mr. Evans and Mr. Monteith have been able to study system recovery curves so much more accurately with the calculating board method that earlier discrepancies become very apparent. We can now begin to deal with the entire recovery curve, rather than with one or 2 points on the curve which are presumed to be critical values but may not be. We cannot easily enjoy the certainty of dealing with the complete facts.

H. G. Brinton (General Electric Company, Pittsfield, Mass.): The Evans-Monteith paper considers the recovery voltage as the sum of 2 components, (*a*) the steady-state component and (*b*) the natural-frequency component.

The first component is sometimes called the restored voltage and is the generated voltage that is suddenly impressed when the 60-cycle inductive drop in generators, transformers, etc., is suddenly removed by the 60-cycle current stopping at zero.

The second component usually rises so rapidly that the first component can be considered as a constant or continuous voltage during the brief period in question. It is the transient voltage appearing on the capacitance in shunt with the circuit opening device when the restored voltage is suddenly impressed on the circuit. In the worst case this circuit is oscillatory and the recovery voltage rises rapidly at the natural frequency of the circuit.

In a 3-phase circuit the first component is sometimes impressed on a rather complicated network. In calculating the recovery voltage conservative assumptions are made so that the actual recovery voltage will not exceed the estimated value which is used in making the application of expulsion gaps or similar devices.

Oscillographic tests may be made on actual service setups and also on miniature laboratory setups. The 2 methods are complementary to each other rather than competitive. The field tests deal not only with recovery voltages under various conditions but also with the life and characteristics of the circuit-opening device and its effect on the system. These field tests are a necessary part of the development and improvement of the circuit-opening device.

Field tests cannot be carried on continuously and miniature laboratory setups afford a valuable means of obtaining a greater amount of data and of broadening out the test program.

A number of field tests on the operation of expulsion gaps and the resultant recovery voltages have been made recently. In general, it has been found that the calculations have been conservative and satisfactory in placing an upper limit on the expected value of recovery voltage. These tests are very valuable in supplying data on the effect of circuit conditions and of variations in the device tested.

In general the factors which tend to increase the recovery voltage are (*a*) limitation of the short-circuit current by inductance principally rather than by resistance so that the generated restored voltage is near a maximum when the current goes out at zero; (*b*) an oscillatory circuit on which the restored voltage is impressed so that the recovery voltage may rise to about twice the restored voltage; (*c*) a small value of the product of inductance and capacitance in the oscillatory circuit so that the natural frequency is high and the recovery voltage rise is steep.

H. M. Trueblood (Bell Telephone Laboratories, Inc., New York, N. Y.): This paper takes a valuable further step in the advance of our means of understanding phenomena which are not only important from an engineering standpoint, but also of great interest in themselves. In some of the studies* that have been carried on by the joint subcommittee on development and research of the Edison Electric Institute and the Bell Telephone System, an important feature has been the matter of overvoltages on power systems at times of ground faults, and the relation of these overvoltages to the use of devices for limiting fault currents. Such investigations make contact at several points with the subject of this paper, and the methods described by the authors should be helpful in them, particularly in the study of specific situations.

The main object of the paper is evidently to present practical working methods, applicable over an enlarged range of practical conditions, and with no more appeal to theoretical considerations than is needed to justify the expectation that the methods described will be accurate enough for engineering purposes. I do not wish to depart from this point of view in discussing the paper, particularly since the involved nature of the subject makes it impossible for theory to go far without clinging to the hand of experiment. The checks that the authors give of results from both methods against measurements on actual systems are gratifyingly good, although they seem rather limited in extent. Additional data from further field work should serve to indicate what modifications may be necessary to insure results within engineering precision, as well as to define the limitations of the new methods as the latter now stand. In view of the rather high frequencies that seem to be important in these phenomena, one matter that may offer difficulty is the determination of the degree of refinement necessary in the equivalent networks. This would be involved in both the analytical method and the use of the calculating board. In the former, in fact, one might run up against another obstacle, arising from the fact that actual power systems are not altogether symmetrical, so that the decomposition into the usual sequence networks is not strictly justified. Unbalances among the 3 networks, unimportant from some points of view at low frequencies, acquire increased significance at higher frequencies. If this sort of difficulty should prove important, it could presumably be taken care of, up to a certain point, in the calculating board setup, at the cost of some complication. The question, of course, is purely one of how much practical difference it would make.

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* Engineering Reports of the Joint Subcommittee on Development and Research, volume IV, pages 105–137 (1937); Gilkeson and Jeanne, "Overvoltages on Transmission Lines," ELECTRICAL ENGINEERING (AIEE TRANSACTIONS), volume 53, September 1934, pages 1301–09.

As I understand, the calculating board used is ordinarily operated at 440 cycles and with impedance elements differing by a conversion factor from the elements of the actual network. I think some further detail about how the board is set up and used in this new application would be of interest, since the results sought go rather beyond the usual range.

R. D. Evans and A. C. Monteith: The discussions indicate that the methods presented in the paper have application to a variety of problems of interest and importance to the industry. The authors are appreciative of these discussions and are encouraged to continue their general study of system recovery voltage and to develop further the methods and their applications.

When a paper describing new analytical methods is presented the discussion is usually concerned with the proper field of application. In the present case the discussion follows these lines. The paper presents 2 general methods of solution and much of the discussion is concerned with the choice. It is the authors' opinion that the simpler circuit problems should be studied by the analytical methods while the more complicated circuit problems and general investigations should be studied by the a-c calculating-board method. The 2 methods can be used to advantage in complementing each other. For the particular problem of opening the last circuit breakers on a bus, we believe that the analytical methods are adequate and not too cumbersome. For such calculation we believe the symmetrical component method of solution described in the paper provides a simplification over previous methods and at the same time gives a better visualization of the various factors entering into the problem.

Several of the discussers have raised a question as to the applicability of a-c calculating-board method for problems involving the higher rates of recovery voltage, basing their view on the limitations of recording apparatus and relative importance of stray capacitance. In this connection it may be observed that the equipment described in the paper for the a-c calculating-board method is suitable for recording much higher natural frequencies than those shown in the few examples. This range can be extended by the use of equivalent circuits of lower natural frequencies, when used with appropriate corrections for the change in the fundamental frequency. By this method difficulties in recording and the effect of stray capacitance are minimized. The limitations of the polar form of recording can of course be overcome by the use of a cathode-ray oscillograph which incidentally was originally developed for surge testing. Thus, for the study of high-speed transients, the a-c calculating-board method is more flexible than would be indicated by some of the discussions. Several discussions have dwelt on the limitation of the a-c calculating-board method in arriving at the recovery voltage for the opening of the last circuit breakers on a bus section. It should be appreciated that there is a large number of other problems in connection with circuit breakers, as well as with other pieces of apparatus on the system for which the a-c calculating-board method is applicable.

Two of the discussers have raised the question as to the frequency used with the a-c calculating-board method. While the board was designed for 440-cycles supply, practically all of the transient studies have been made with a separate 60-cycle supply although some studies have been made with other lower frequencies such as 25 cycles.

Doctor Trueblood's discussion is valuable in bringing out the multiplicity of factors entering into the recovery voltage problem and the technical difficulties involved in the circuit problem. He has ably summarized the authors' approach to the problem which has been to provide a practical method giving engineering accuracy. We are in hearty agreement with Doctor Trueblood, Mr. North, Mr. Brinton, and others, on the desirability of obtaining further system tests to establish benchmarks which are themselves valuable and which will provide a sound basis for broader analyses by the methods presented.

Mr. North's discussion is valuable in that it emphasizes the fact that there are a number of pieces of apparatus whose performance is vitally affected by recovery voltage characteristics. He has also raised the question of the method for reducing an extensive power network to a relatively simple equivalent. It is difficult to formulate a general procedure since to a considerable extent each network must be considered as a special case. In general, the complicated system may be set up on the a-c calculating board in a manner similar to that used for load studies when line capacitances are taken into account, with the additional complication of setting up the network on a 3-phase basis and making the zero-sequence circuit of proper value in a manner similar to that shown in figure 15. In the case of very large networks it may be necessary to set up at one time only a part of the system and to obtain an equivalent network for this part.

We agree with Mr. North that the reference in figure 27 should be to figure 18 instead of figure 19.

Mr. Skeats has suggested that recovery-voltage characteristics for circuits and apparatus be defined in terms of the rate of rise to certain points on the recovery voltage wave. The authors are of the opinion that a better and more complete picture of the voltage recovery problem both from the standpoint of the system and of the apparatus will be obtained by the method used in the paper which defines the recovery voltage in terms of a curve plotting magnitude and time. Having such a curve in mind it is convenient to express particular points of interest in terms of magnitude and time to crest. The phenomenon of arc interruption reviewed by Mr. Ludwig is a subject which must be thoroughly understood in order to broadly consider the recovery-voltage problem.

Mr. Skeats' point concerning the connection of the sequence networks is not clear. It is assumed that he refers to the fact that a switching operation is required for changing the connection of sequence networks when representing the opening of one pole of a breaker on a double-line-to-ground fault. This is a complication with the sequence network method of representation but it is of course not encountered with the 3-phase method which has been more generally used by the authors. The sequence network, however, does assist in separating the components of the total recovery voltage and thus gives a better visualization of the phenomena taking place.

Mr. Skeats suggests that the machine reactance used in recovery studies should be based on the quadrature subtransient reactance on the basis that the current is interrupted at the crest of the voltage wave at which time the flux path in the rotor is in the quadrature axis. However, the recovery phenomenon generally of interest is that corresponding to the clearing of some unbalanced fault on the transmission system and for such conditions the flux path in the rotor will not be wholly in the quadrature axis. Hence some combination of the reactances corresponding to both direct and quadrature axes should be used. The negative-sequence reactance is an average of these reactances and was suggested in the paper as the value to be used in recovery voltage investigations. A more important correction than the cyclic variation in reactance may be due to the harmonic distortion which occurs with unbalanced faults on salient-pole machines without dampers. This point, mentioned by Mr. Crary, has been recognized by the authors. The effects of harmonic distortion are admittedly difficult to include in setup but can be compensated for by separate correction. The use of such a procedure for this very special case is believed to constitute only a minor limitation to the general value of the method.

Mr. Crary has also raised a question of the fault representation for the interruption of an arc at other than its normal current zero. If the arc characteristics are known, a fault representation device may be devised and its effect introduced into a calculating-board study. One such arc representation device is described by the authors in connection with figure 18. The a-c calculating-board method permits interruption at any desired point. As pointed out by the authors, interruption of an arc on a system will ordinarily take place at or close to the normal current zero because of the fact that the recovery voltages for interruption on either side of this point are higher than at the normal current zero.

In connection with Mr. Hunter's discussion, we do not understand the difficulties which he anticipates in the determination of circuit constants for systems on which flashover protector gaps are to be applied. It is our opinion that if the physical layout of the system is known the electrical constants may readily be calculated with engineering accuracy.

Characteristic Constants of Single-Phase Induction Motors

Discussion and author's closure of a paper by Wayne J. Morrill published in the March 1937 issue, pages 33–38, and presented for oral discussion at the power generation and electrical machinery session of the summer convention, Milwaukee, Wis., June 24, 1937.

P. L. Alger: See discussion, page 1312.

P. H. Trickey (Diehl Manufacturing Company, Elizabethport, N. J.): I was very much interested in Mr. Morrill's paper partly because of its usefulness and partly because he has used a similar method of attack to that used in my paper on shaded-pole motors.

In checking the 2 papers against each other, I find several points of interest. In the first place in my own paper the first sentence of the paragraph on harmonic reactance should read "The above reactance X_m is here defined as the magnetizing or mutual reactance." In the second place, after taking the differences of the total and magnetizing reactances, the terms were rearranged, and the term $\sin^2 \beta/_2$ was inadvertantly omitted from the denominator of the constant C_h which should read

$$C_h = \frac{1.232\ \alpha - \mathrm{Sin}^2\ \beta/_2}{\mathrm{Sin}^2\ \beta/_2}$$

Having made this correction and putting the constant 3.19 in Mr. Morrill's equation for permeance, it can be shown that the 2 equations became identical for the special case of one coil per pole with a pitch equal to the pole area of the salient-pole motor.

In developing these formulas, I feel that Mr. Morrill has very definitely contributed to the more accurate calculation of motor constants. The formulas which my associates were using when I first began to calculate motors, were the original formulas of C. A. Adams, published in 1904. However, to partly compensate for a wide divergence between calculation and test, they were using Adams' "belt leakage" even on squirrel-cage motors. After Mr. Veinott developed the formulas for skew leakage, and after I had worked up some curves for the reactance of closed-slot rotors, we attempted to drop the fallacious use of the belt leakage. We found that we were always low if we omitted it and high if we used it. So for a number of years now we have been arbitrarily using $^1/_3$ of the calculated belt leakage, and have had very satisfactory results. We have justified it, as partly compensating for some differential leakage not covered by the zigzag.

I have lately checked 4 repulsion-start induction motors, comparing the present method of zigzag plus $^1/_3$ belt to Mr. Morrill's stator and rotor harmonic leakage.

In all the cases; the present method, Mr. Morrill's method and test values were very close together, but in every case Mr. Morrill's method was closer to test than the present method.

Mr. Morrill has given us some very useful formulas which can be applied directly to repulsion-start induction motors. Would it be out of place to ask him if similar formulas are available for the rotor reactance of the squirrel-cage rotor?

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Wayne J. Morrill: I am pleased to receive the discussion from Mr. P. H. Trickey, announcing close agreement between calculation and test which had been obtained by him using the method of my paper.

Mr. Trickey asked whether similar formulas are available for the rotor reactance of squirrel-cage rotors. It was my intention to point out in the paper that the developed formula for rotor-air-gap reactance applies equally well to squirrel-cage rotors and wound rotors.

End-Winding Inductance of a Synchronous Machine

Discussion and author's closure of a paper by B. H. Caldwell, Jr., published in the April 1937 issue, pages 455–61 and 474–5, and presented for oral discussion at the power generation and electrical machinery session of the summer convention, Milwaukee, Wis., June 24, 1937.

G. W. Hampe: See discussion, page 1318.

P. L. Alger (General Electric Company, Schenectady, N. Y.): The appearance of the 4 papers by Beckwith, Caldwell, Douglas, and Morrill, carrying further the analytical study of leakage reactance, and the recent appearance of an article on "Induction Motor Leakage" by Mr. L. H. Carr (Metropolitan Vickers Gazette, volume 16, May 1937, pages 426–31) indicate that there is still much to be done in making the knowledge of this important subject adequate for design purposes. Professor Douglas' suggestion of procedure for end-connection reactance calculation, and Mr. Caldwell's actual carrying out of such a process for the end leakage reactance of synchronous machines, are particularly important contributions. I believe that Mr. Caldwell's results are more exact and give a more satisfactory understanding of the variations of end leakage reactance with design proportions than any methods heretofore published. Further work in this field is still desirable, however, first to verify the practical application of his results over a wide range of machines, second to add methods of allowance for the additional reactance due to the presence of magnetic retaining rings, such as are used with high-speed machines, and third to determine the end reactance when the secondary currents flow in a distributed armature winding or a squirrel cage, instead of in a salient-pole field winding.

I also believe that Mr. Morrill's contribution in presenting a method of more accurately calculating the air-gap reactance of single-phase motors is important. The results in some ways conflict with those obtained by Mr. Carr in the paper mentioned above, Mr. Carr preferring the method of calculating the average overlap of the teeth to obtain the permeance of the combined zigzag leakage flux paths, instead of using the difference between the total air gap flux and the fundamental component for rotor and stator separately, as used by Mr. Chapman and Mr. Morrill. Also, Mr. Carr suggests that the variations in the air gap fringing coefficients for the fundamental and the tooth harmonic fluxes introduce an error when Mr. Morrill's method is used. While further work should be done to reconcile these different views, my own belief is that Mr. Morrill's method is substantially correct.

Another problem to be solved in this reactance calculation field is that of determining the leakage reactance for various types of irregular or multiple windings, such as are used in part-winding starting of motors and double-winding operation of alternators. These windings have relatively large air-gap leakage reactance components due to the large harmonics in the field form, and they also have additional slot reactance, depending upon the arrangements used, as discussed in the paper presented before the Institute in 1929, entitled "Double Windings for Turbine Alternators (P. L. Alger, E. H. Freiburghouse, and D. D. Chase, AIEE TRANSACTIONS, volume 49, January 1930, pages 226–44). I believe that the orderly system of notation and the use of connection tensors, suggested by Mr. Kron, are helpful in analyzing these problems of irregular windings, and I hope that a paper can be presented before the Institute dealing with this aspect of the subject in the near future.

J. F. H. Douglas (Marquette University, Milwaukee, Wis.): Caldwell's fourth assumption, namely that there is 100 per cent eddy-current shielding in the end laminations, is equivalent to the use of a Rayleigh insulating surface, and is a conservative assumption. Thus his values of inductance are smaller than the true values, but if they are, as indicated by the discussion, higher than previous published values they are nearer the truth.

With regard to the factor (2) which disappears between Caldwell's equations 12 and 15 I believe that this is the point he chooses to introduce the effect of both end windings, and that his equation 15 is substantially correct.

It should be pointed out next that the writer has carefully checked the various formulae as far as equation 25 and suggests a slight modification only in equations 13 and 23. Thus the work appears to be substantially accurate and in accordance with the postulates. The method is, moreover, of considerable power, and leads to convergent series and a workable formula for inductance.

The capabilities of the method, transcend the postulates, Caldwell's third postulate is equivalent to placing a Rayleigh conducting plane tangent to the ends of the winding and increases the inductance perhaps 5–10 per cent. By moving the plane away from the poles and using a double harmonic series as is used in the theory of the square drum head this error may be reduced ["Fourier Series, Surface, Zonal, and Spherical Harmonics" (a book), Byerly].

Caldwell's fourth postulate, namely that of 100 per cent eddy-current shielding may be replaced by its opposite 0 per cent shielding and the method would still be applicable. In figure 1 is shown a wave of magnetomotive force varying in the y direction, the right-hand wave and the left-hand dotted wave are in accord with Caldwell's fourth postulate, the solid curve indicates the needed change to make the polar and armature iron an equipotential surface. P represents the poles, A the armature, FC the fictitious conductor closing the gap, and RC represent Rayleigh conducting planes. The series of harmonics is now a double series, contains terms of double frequency only in y and converges more slowly than before. Thus Caldwell's method should be capable of considerable further development.

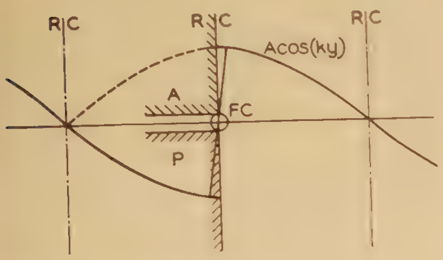


Figure 1. Magnetomotive-force wave with no shielding

Comment should be made on the ingenious experimental technique shown in figure 10. This is believed to be a very useful contribution. In this figure it appears as if the long side of the triangular test coils returns on the outside of the end connections. It is believed that this misses considerable flux, and that the correct location of the return conductor should be on the air-gap side of the end connections and adjacent to the tips of the teeth.

One important consequence of Caldwell's analysis, and equally true even when different postulates are used, is that the field is essentially a cosine function of x. This means that the field in the end zone is substantially a revolving field for either positive-or negative-sequence components, and a pulsating field for zero-sequence currents.

I wish here to record my reasons for believing that Caldwell's fourth postulate of 100 per cent eddy-current shielding is needlessly conservative. This is an important point, since a particular case showed decidedly greater inductance with 0 per cent shielding. The largest difference is made by flux leaving ends of stator teeth and reaching the pole shoe. Here there is no shielding in the rotor as it moves synchronously with the flux (positive sequence assumed) and little shielding is offered by the teeth as they are too constricted for eddy currents. In the second place the flux leaving the side of stator laminations is undoubtedly cut down somewhat by eddy currents, but it is suggested that flux penetrating only 2 or 3 laminations would find an easy return path, and the shielding should not be large. There is enough evidence available from the loss caused by lapped-over butt transformer joints, and in the reactance of core-type transformers to estimate the probable shielding of eddy currents. Caldwell's assumption is nearer correct for cross-magnetizing flux than direct, nearer for negative and zero phase sequences than for positive. It is suggested that further experiments are very much needed.

In commenting on Caldwell's figure 11 the solution of a particular case indicated the plane aa' to be nearer the end connection than the pole core, I conclude that Caldwell's fringing is an important factor, and as pointed out it could be calculated as part of the end-zone flux.

In place of the author's equation 13 for pitch other than 100 per cent I get the magnetomotive force as a double summation of surface harmonics of the type

$$M = \sum_{n=1}^{n=\infty} \sum_{m=1}^{m=\infty} A_{mn} \times \cos(mxP/D) \sin(nky) \quad (1)$$

where the value of A_{mn} is given by

$$A_{mn} = \frac{32\,(ni)\,(p) \cos(1.57\,mp)}{(3.14)\,(m)\,(n^2 - m^2p^2)} \sin(1.57n) \quad (2)$$

This reduces to the form of Caldwell when there is 100 per cent pitch. We request Caldwell to give more details in his discussion.

In attempting to check Caldwell's equation 23 I get a slightly different result. Calling k the ratio of slot width to tooth pitch,

$$K_m = K_{pm}K_{hm}' \left(\frac{3}{3.14m}\right)^2 \times \left(\frac{\sin(km30°/s)}{k \sin(m\,30°/s)}\right) \quad (3)$$

It is believed that the neglect of the last term in equation 3 introduces an error less than 10 per cent with the postulates adopted by Caldwell, but with 0 per cent shielding, and a less rapidly converging series the term may be of consequence.

Ernst Weber (Polytechnic Institute of Brooklyn, Brooklyn, N. Y.): The general outline for the computation of the reactance of end connections as given by J. F. H. Douglas, is extremely interesting and certainly opens a wide field for experimental as well as mathematical research. The specific application of mathematics to this particular problem exposed in the paper by B. H. Caldwell illustrates the power of the judicious combination of theory and experiment. There are, however, a number of points to be considered in a more thorough study of this leakage problem. The Fourier series employed by Caldwell presupposes an infinite grid system of square loops. In reality, taking into account the magnetic image of the end coils one would have a single infinite line of diamond-shaped coils and the Fourier-integral method should be employed to obtain the proper field distribution perpendicular to the magnetic mirror. The apparent agreement between measured and computed values might be essentially due to the simple geometric form used. This agreement fails immediately when measurements are made on completed machines as evidenced in table II of the paper, where the error in the mutual inductance is 29 per cent and the error in the self-inductance 13 per cent.

On account of the simplifications introduced by Caldwell, one cannot possibly expect his formulas to hold in actual machines. I should like to call attention to a very thorough study of this problem extending over a period of almost 15 years, which leads to formulas taking into account all the details of actual machinery. The mutual linkage, for example, between field coil and stator winding is taken into account there and not ignored. I am referring to the set of volumes "Elektrische Maschinen" by R. Richter, successor to E. Arnold, at the Technical University "Fridericiana" in Karlsruhe, Germany. Four volumes have appeared, published by J. Springer, Berlin, Germany. The first volume, dealing with the general elements of electrical machines, published in 1924 (price approximately $11.00), gives on page 281 an exposition of the general problem of end-connection leakage. Some of the salient points of Richter's presentation are: distinction of the useful flux (linked with stator winding and field coil or rotor winding in general) and true leakage bux; computation of the leakage inductances by means of Biot-Savart's law in its form modified by J. C. Maxwell; distinction between self- and mutual inductances of the stator coils taking into account the relative position for the various types of windings used in electrical machinery, and finally a general form for the specific end-connection leakage whereby factors are introduced obtained by experimental research on a large variety of coil models, executed in the laboratories of the Technical University of Karlsruhe under the supervision of R. Richter.

Volume 2, dealing with the synchronous machines and synchronous converters, published in 1930 (price approximately $12.60), gives on page 91 a general formula for the specific end-connection leakage, introducing correction factors taking into account the shape of the rotor, the combination of the coils into coil groups and the pitch of the individual coils. Curves are given for those correction factors which were determined experimentally.

Volume 4, dealing with synchronous machines, published in 1936 (price approximately $12.60), gives on page 161 the application of the general formula for the end-connection leakage to the types of windings used in asynchronous machines, and takes into special consideration squirrel-cage rotors and slip-ring rotors of various numbers of phases. Again, distinction is drawn between useful flux and individual leakage flux of the opposing windings and correction factors are given in table and graph form.

Since the formulas published in the set of volumes mentioned above have been checked carefully in the course of many years, and since the resources of the Technical University of Karlsruhe are of world-wide repute, it might be very valuable to compare the results there obtained with the procedure suggested in the papers before us.

Leroy Coffin (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): The subject of end-winding leakage reactance is of particular importance to designers of rotating electrical machinery because it forms an elusive part of the more important reactances. It may be a considerable part of the transient and subtransient reactances, particularly in machines with short cores, and for that reason the determination of these reactances may depend largely upon how closely the end-winding leakage reactance may be estimated.

Mr. Caldwell has made a very ingenious mathematical analysis of the end leakage field and it appears that with some modification to cover particular cases that we are now nearer a solution of this problem.

A flux map of this end-winding region shows a portion of useful flux extending well out into the space occupied by the coil ends and entering the stator teeth and core. The existence of this flux may be verified by means of iron shavings placed in a glass test tube. While this component of useful flux may be small in comparison with the flux in the air gap it is not necessarily small in relation to the total flux existing in the end zone. Each end conductor is also linked with flux which does no useful work. This we term leakage flux. We attempt to calculate the amount of this leakage flux but there is no way of readily measuring it. Exploring coils may fail to link all the leakage flux and are usually cut by useful flux. We thus measure the total flux, cutting the exploring coil but have failed to divide it into its respective components.

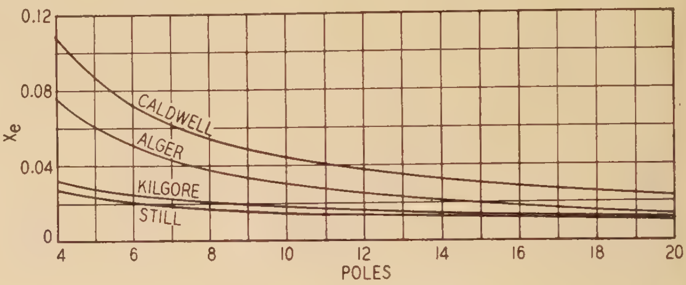
Most machines have masses of iron in this end zone, such as core end heads or finger plates, coil shields or end bells, and pole end plates or rotor-coil support rings. These, of course, change the reactance and their presence will require correction factors which will necessarily be empirical.

Caldwell's equation 16 gives values higher than those calculated by the usual methods. Calculations were made on a number of 3-phase machines, varying from 4 to 88 poles and in no case did the mutual leakage exceed 3 per cent to 4 per cent. A great many salient-pole machines have rotor pole end plates extending well out into this end zone. It would not seem that any appreciable amount of mutual leakage flux could exist between the 2 windings with this magnetic material between them.

In order to compare the various methods of calculating this end-winding leakage a hypothetical case was considered. It was assumed that we had a core which could be wound for 4 to 20 poles. The air-gap flux density, effective ampere conductors, and the output factor were arbitrarily kept constant in order to make the results comparable. Low-voltage insulation was assumed. Figure 2 shows the calculated per unit values of end-winding leakage reactance for a full pitch winding. The calculations were made by Caldwell's method and previously published methods.$^{1-3}$ No allowance was made for mutual leakage. No multiplying factor has been applied to the values obtained by Still's method. He recommends a figure of 1.7 to 3.5, depending upon the type of machine. Figure 3 shows calculated values for the same machines wound with $^2/_3$ pitch. This shows the influence of short pitch on the various methods. This example does not mean that the variation by different methods will always be as shown here. The results depend upon the amount of insulation on the coil, the ratio of slot to tooth width, the angle of the V part of the coil, and various other factors. However, with the various methods now available, used in conjunction with tests on actual machines, the designer should be able to estimate this end-winding leakage reactance with reasonable accuracy.

Figure 3. Comparison of end-winding leakage reactance calculated by different methods

2/3 coil pitch



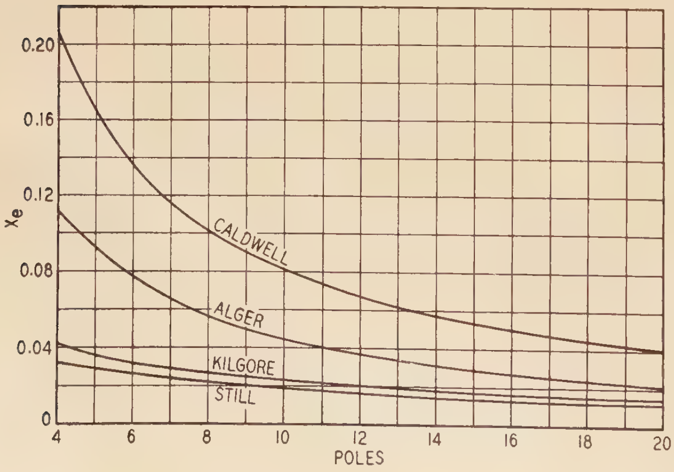


Figure 2. Comparison of end-winding leakage reactance calculated by different methods

Full-pitch winding

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2. END CONNECTION REACTANCE OF SYNCHRONOUS MACHINES, Alfred Still. AIEE JOURNAL, July 1930.

3. CALCULATION OF SYNCHRONOUS MACHINE CONSTANTS, L. A. Kilgore. AIEE TRANSACTIONS, volume 50, page 1201.

B. H. Caldwell, Jr.: The appearance of the factor 2 in equation 15, which has been questioned by Mr. Coffin, has been carefully checked both by Mr. Douglas and the writer, and the conclusion is that with the stated assumptions (15) is correct as it appears in the paper. In proceeding from (12) to (15) a multiplier of 2 does appear to take account of both ends of the end winding.

There may be some confusion regarding the definition of n. Perhaps a clearer definition would be to define n as the number of V-shaped end-winding conductors per phase per pole. Throughout the paper the V-shaped conductor has been used as the unit. This corresponds to the number of series connected turns of the armature winding as a whole.

There happens to be an easy way of comparing the result given by (15) with Mr. Alger's result (reference 1 of the paper). His equation 13 for the peripheral component of end-winding leakage flux, when expressed in the nomenclature of this paper, is

$$\frac{X_{EP}}{2\pi fP} = \frac{12\pi D\tan\alpha}{P}K_{pl} \qquad (1)$$

Equation 15 differs from (33) only in that the tan α is replaced by sec α. For $\alpha = 60$ degrees the ratio of (15) to (33) is 1.155. Now Mr. Alger adds the axial component of end-winding leakage to X_{EP} to obtain the final expression for the total leakage, while the mutual linkage is subtracted from (15) to obtain the final expression for the leakage inductance, hence it appears logical to expect the 2 methods to agree with fair accuracy.

Mr. Douglas calls attention in his (1) and (2) to an approximation not specifically mentioned in the paper. The approximation involved is equivalent to assuming curve 1 of figure 4 instead of curve 2 as the magnitude of the space fundamental of flux density along the y-axis. Curve 2 which is theoretically correct has its maximum at

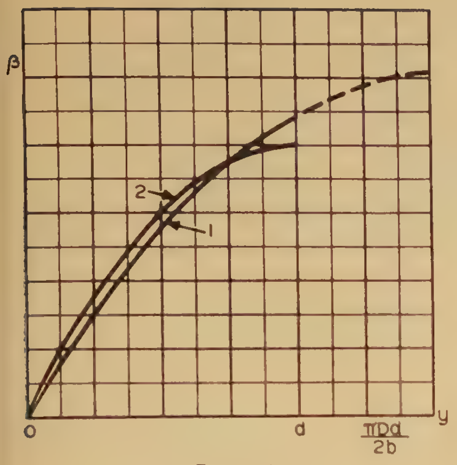


Figure 4

$y = d$, while the assumed curve 1 has its maximum beyond $y = d$. Only the region between $0<y<d$ is involved, and the simplification of the expression for the pitch factor warrants the approximation. For $^3/_4$ pitch this introduces an error of about 3.5 per cent.

The approximation pointed out by Mr. Douglas in his equation 3 is specifically noted in the paper. Space limitation prevented discussing it in detail. As he points out, it may lead to considerable error in some cases, particularly where the ratio of slot to tooth pitch is large. However, Mr. Douglas apparently overlooks the fact that, because of the angle of the end connections, the ratio of the peripheral dimension of the conductor in the end zone to the tooth pitch is much closer to unity than it is in the core length, which makes the approximation quite good for the fundamental. In cases where the series of equation 22 converges slowly equation 21 instead of 23 should be used to compute K_m.

Both Mr. Coffin and Mr. Douglas have pointed out the importance of fringing flux across the air gap. Measurements with exploring coils as well as flux plots indicate that they are correct. I would like to refer them to the discussion of this under "conclusions" in my paper. What I have attempted to calculate and measure is end winding *leakage* inductance. It seems obvious that practically all of the flux lines which enter either the pole directly or the rotor pole end plates will thread the pole coil, appear as fringing flux at an adjacent pole, and complete their paths by returning through the stator iron. There is, of course, some flux which passes from a tooth side to the adjacent tooth side. This is truly leakage flux and F. W. Carter in a discussion of a paper, "The Reluctance of Some Irregular Magnetic Fields," J. F. H. Douglas, AIEE TRANSACTIONS, volume 34, 1915, pages 1067–1134, has calculated this as a correction for the slot leakage flux. This seems to be a logical way to handle the other components of fringing flux. Thus this flux would contribute components to the flux of armature reaction and differential leakage as well as the slot leakage. Except for machines with a very short stacking these fringing components would probably be a very small correction. On this basis I have chosen to ignore the fringing flux in calculating the end-winding leakage inductance, and it enters the problem only in that it distorts the end-winding leakage field.

In the exploring-coil method of measuring the end-winding leakage inductance this question of fringing flux again appears. As Mr. Douglas points out, the exploring coils are not linked by all of this fringing flux. However, they were in the same positions for both the measurement of the self and the mutual flux, hence the omitted part would add to each of these values in the same way and cancel in the final result.

It is not my purpose to minimize the importance of calculating the fringing flux. Although it does not, according to the postulates of my paper, constitute a part of the end-winding leakage flux and except in rare cases the corrections of slot leakage, differential leakage, and inductance of armature reaction to account for it are probably small, it is very important in calculating losses. Most of this flux enters unlaminated sections of iron, hence it is probably responsible for a large part of the magnetic losses of machines.

For this reason, further work along the lines suggested by Mr. Douglas is very desirable. Also, as Mr. Alger points out, the method outlined should be useful in calculating the inductance of a larger class of machines. The discussion of this group of papers has revealed many useful suggestions and it is to be hoped that these suggestions will be the subject of further theoretical and experimental study by the various authors.

Reactance of End Connections

Discussion and author's closure of a paper by J. F. H. Douglas published in the February 1937 issue, pages 257–9, and presented for oral discussion at the power generation and electrical machinery session of the summer convention, Milwaukee, Wis., June 24, 1937.

P. L. Alger: See discussion, page 1312.

G. W. Hampe: See discussion, page 1318.

Ernst Weber: See discussion, page 1313.

L. T. Rosenberg (Allis-Chalmers Manufacturing Company, Milwaukee, Wis.): The designer is always eager to adopt refinements in methods of calculation of performance that will consistently yield more accurate values. Heretofore, end-connection reactance has been computed on the basis of certain assumptions which gave reasonably good results in most cases. When test values of reactance showed poor agreement with calculation, it was not always easy to determine the exact source of the error, although it was only natural to suspect those places where approximations had been used.

In synchronous machines having magnetic rotor pole end plates with axially overhanging pole piece to support the rotor coil ends, and in turbogenerators not equipped with nonmagnetic rotor-coil retaining rings, the proximity of the magnetic material evidently had its effect upon the end-winding reactance. Since these effects are most pronounced in the immediate vicinity of the core and pole ends, and since in machines of moderate to large ratings the stator coils usually project straight out of the slots for a distance of from 2 to 6 inches and then bend radially outward at an angle, it would seem reasonable that end-connection reactance might well be divided into 2 distinct parts; that part corresponding to the straight stickout with the proximity of iron accounted for in accordance with Doctor Douglas' paper, and the remainder corresponding to the V-shaped ends considered to be far enough away from the iron to be unaffected as treated by B. H. Caldwell in a companion paper. A rigid solution on this basis may prove to be less difficult and thus permit taking account of the conical shape of the end winding plane.

The application of the Schwarz-Christoffel transformation to the solution of magnetic fields as described in the paper will generally lend itself to the expression of permeances as a function of the physical dimensions in the form of curves, thus facilitating practical use of the results. End-connection reactance might then be computed in very much the same manner in which we now use the Carter coefficient to calculate the effective air gap of a slotted armature surface.

J. F. Calvert and **E. K. Rohr** (Iowa State College, Ames): We have several items which we wish to discuss in connection with Professor Douglas' paper and will introduce these approximately in the order in which he has presented them.

1. In his discussion of figure 2 of the paper, he describes how ampere turns applied across the air gap may be replaced by current-carrying conductors of proper strength. However, for his figure 1 and the lower view shown in figure 5, where imaging is proposed, we would like to ask why the air gap magnetomotive force has not been replaced by a current sheet (or Rayleigh insulating surface for magnetic flux)?

2. Referring now to the right-hand drawing in figure 2 of Professor Douglas' paper, we do not believe that this presents a strictly correct treatment of the problem. Either it must be assumed that other conductors exist such that there will be the same magnitude of magnetomotive force for the air gap over each coil, or else, if only one coil is to be assumed in the air gap, as is shown in his figure 2, the return current at the air gap for the single coil end must divide and travel along the air gap in 2 paths. This is illustrated further in figures 1 and 2 of this discussion. If only one coil is to be assumed in the machine and it spans one-fourth of the air gap periphery, figure 1*a* of the discussion shows the air gap magnetomotive force to be replaced, and figure 1*b* shows how this should be accomplished. If 4 coils, each of one-fourth pitch, are to be assumed and are so disposed that the magnetomotive force on the air gap is symmetrical, figures 2*a* and 2*b* of this discussion show how the air gap magnetomotive force should be replaced by current-carrying conductors. We assume that for the right-hand drawing of figure 2 in the paper, Professor Douglas is assuming that

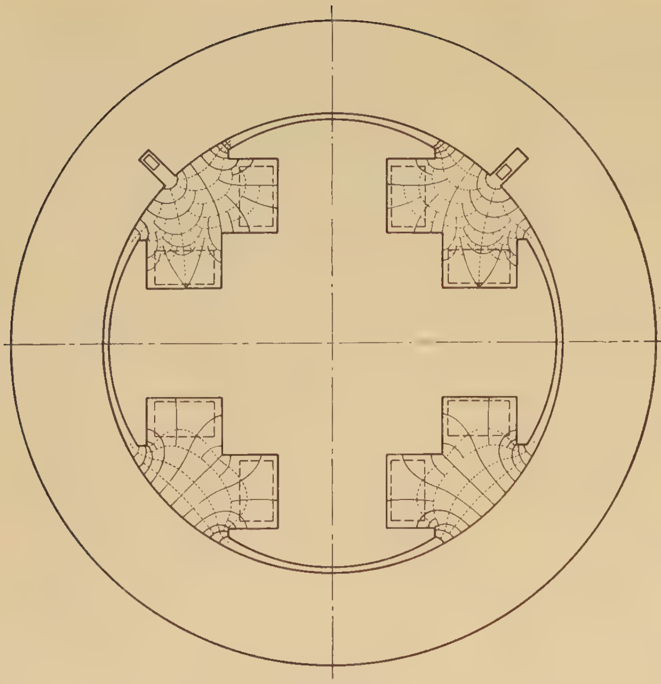


FIGURE 1a

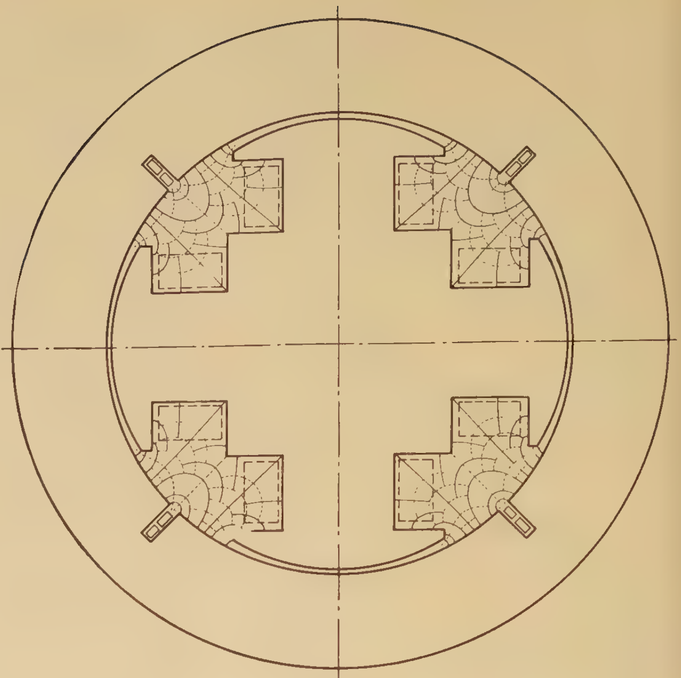


FIGURE 2a

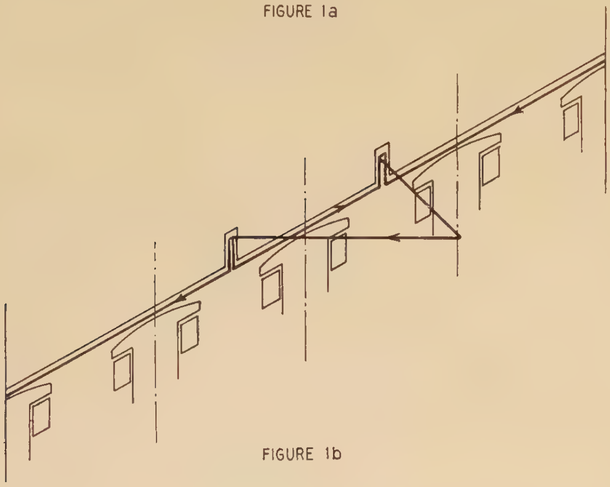


FIGURE 1b

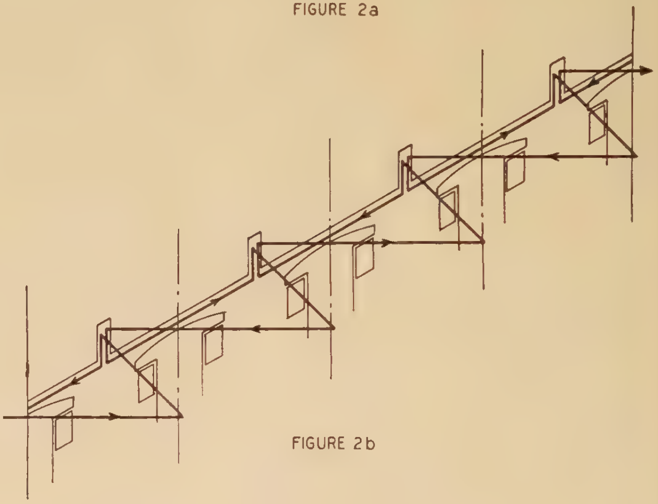


FIGURE 2b

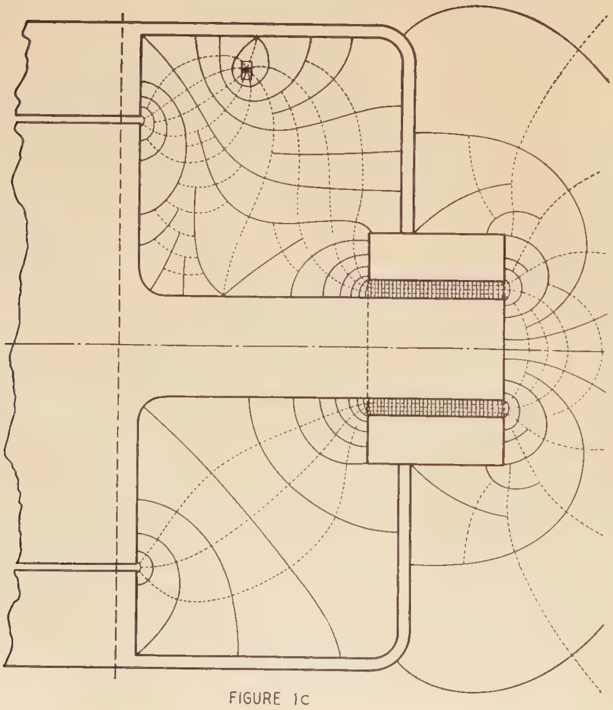


FIGURE 1c

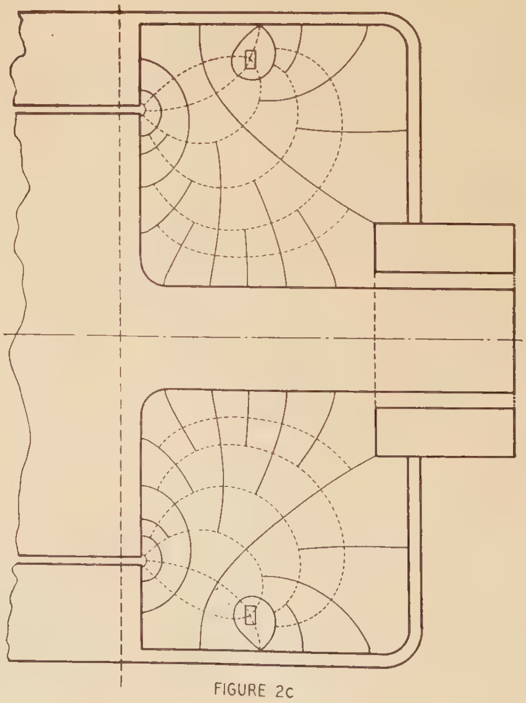


FIGURE 2c

Figure 1a. Only one full pitch coil excited

Solid lines show the flux. Dotted lines show the ampere turns, and also the directions and relative densities for the current when the air space in this plane is replaced by a current sheet or Rayleigh insulating surface for magnetic flux

Figure 1c. Approximate flux and magnetomotive-force distribution on the radial plane through the pole center line with only one full pitch coil excited in a 4-pole machine

Note the map is only 2-dimensional. Also note that the stator finger-plate and end-plate and also the overhang on the pole end-plate are neglected to give a plane surface and thereby permit imaging. This has been done to be most nearly in conformity with the paper

Figure 2a. Same as figure 1a except with one full-pitch coil per pole excited as shown

Figure 2c. Same as figure 1c except for one full-pitch coil per pole

an even number of coils are disposed around the machine in a manner similar to that indicated by figures 2*a* and 2*b* of this discussion. Figures 1*c* and 2*c* of this discussion show the end zone flux mapped on the assumption of a 2-dimensional field. It must be recognized that a 2-dimensional analysis here is only approximate, but it does give the general direction of the magnetic flux, and the orthogonal surfaces.

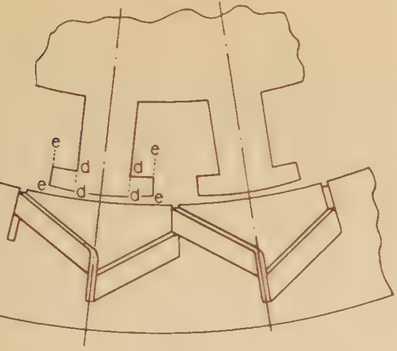


Figure 3

3. In his discussion of figures 5 and 6 of the paper Professor Douglas assumes a Rayleigh insulating surface to be located in a plane parallel to the edge of the field poles. It would appear that Professor Douglas intends to neglect the pole overhang or pole-shoe. However, we would like to ask first whether this Rayleigh insulating plane is to be assumed at *e-e* or at *d-d* as designated in figure 3 of this discussion, or at some intermediate location, and second on what basis a Rayleigh insulating surface in this zone between *e-e* and *d-d* can be assumed to be a plane? We feel that this assumption is an ingenious development, and if it can be adequately justified may prove to be a useful artifice, but we also feel that further justification for the assumption of a plane for this surface should be presented.

4. The pole and armature present Rayleigh conducting surfaces for magnetic flux in the end zone. However, the interpolar space may be considered merely as a widening out of the air gap in the radial direction. Therefore, in the polar zone as defined in the paper, the pole and armature do not form a continuous Rayleigh conducting surface, but must have a Rayleigh insulating surface between them to represent the air gap as illustrated in figure 3 of this discussion. That this must be done, is not made clear in that part of the paper in which figure 5 of the paper is discussed.

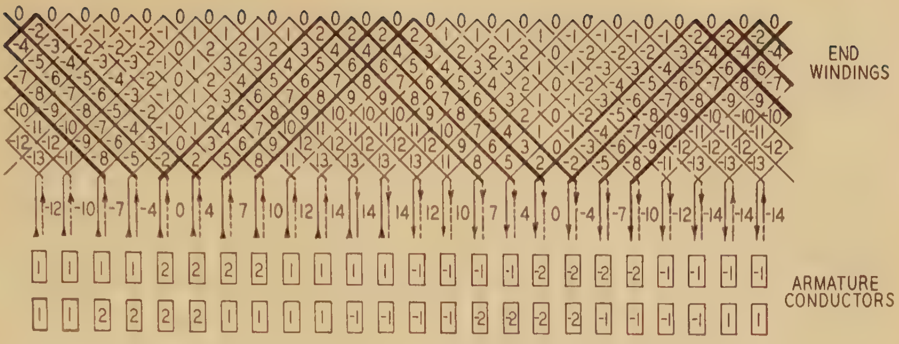


Figure 4. End-winding and air-gap magnetomotive forces

Three phase, 4 pole, 48 slots, coil span = 10 slot pitches

5. The use of the Rayleigh conducting surface RC_2 in the lower right-hand corner of figure 5 of the paper would seem to be a reasonable assumption for those machines in which the frame and end bracket overhang the coils, and do present such a conducting surface for magnetic flux over both the polar and interpolar zones. However, the assumed plane should be so located as to most nearly represent these magnetic parts. It may need to be closed in on machines with bracket-type bearings making reasonable allowance for the space between bracket arms. (See figures 1*c* and 2*c* of this discussion which are for a machine where the actual bracket arms came outward on diagonal lines from near the frame to the bearing.)

6. To be in conformity with the paper, we have confined our discussion to the case of one full-pitch armature coil per pole. We wish now to discuss the actual cases of distributed windings. Exploring coils will show that the flux lines pass through the armature end winding in directions reasonably nearly perpendicular to the conical surface between the 2 layers of the end winding. Reasons for this can be offered.

If no iron were present at all and the coil span was not a great percentage (one-fourth or less) of the armature bore, then the reluctance inside and outside the coil would not be greatly different and the flux field near the conical surface of the end winding would be almost symmetrical with respect to this conical surface. This would mean that the flux would pass nearly perpendicularly through this surface between 2 layers of coils in the end winding. The introduction of iron into the problem produces tremendous effects where it is near the coils. However, it is not near the conical surface of the end winding and will not produce great effects here just as the imaged conductors with the iron removed would not produce great effects on densities near the coil which is imaged—provided the spacings between coil surface and iron are relatively great as is the case for most of the armature end winding.

It might be desirable to make use of the magnetomotive forces through this surface at various points as mentioned before. The end zone like the air gap and interpolar zone is merely part of the air space between the rotor and stator. On the basis of these 2 remarks, it might seem desirable to extend the usual magnetomotive-force diagram for the air gap to the end zone as is illustrated in figure 4 of this discussion. This viewpoint has been discussed in more detail in the paper "Additional Losses in Synchronous Machines," AIEE TRANSACTIONS, volume 46, 1927, pages 84–97, by C. M. Laffoon and J. F. Calvert. We offer this merely as a possible treatment. We wish to point out that our figure 4 of this discussion merely gives the approximate magnetomotive force distribution and not the reluctance for paths through the winding. The effects here might be considered analytically by assuming the magnetomotive-force distribution mentioned above and considering the iron boundary conditions as they exist in the end zone. Another possible attack would be to excite the armature coils with direct current, and explore the directions of flux with a compass. The discussers are of the opinion that the experimenter would then deduce that exploring coils placed within the conical end winding would show practically the total linkage in this zone under a-c conditions. The flux distribution under these d-c conditions will be practically the same as under normal a-c conditions because sufficient eddy currents cannot flow in the armature end plates and frame to alter greatly the flux distribution under normal load. That this must be true can be reasoned as follows: The armature winding carries the full armature magnetomotive force in the end winding. If the flux is to be kept out of the end plates, frame, etc., damping currents of practically equal magnetomotive force would have to flow in these parts. When one considers the depth of current penetration in the iron which is normal at the commercial frequencies, the loss densities are many times higher than can actually exist without greatly overheating the machine. Another method of attack here is to neglect saturation and calculate by means of 2-dimensional flux maps what the flux entering the iron parts will be. Then calculate the saturation produced making due allowance for proper flux penetration in solid parts. Then by use of Rosenberg's formula consider the ampere turns present in eddy currents. These eddy currents will be found small enough to have little effect on the general shape of the end zone flux.

We hope that Professor Douglas will give a detailed discussion of how he intends to consider the various phase groups in the end zone either with or without the use of the Rayleigh insulating plane to divide the space into polar and interpolar spaces when he proceeds to the cases of actual armature windings.

7. In addition to the use of Rayleigh insulating and conducting planes as Professor Douglas describes them, we wish to suggest that any surface in a magnetized space may be replaced by combinations of current and magnetic sheets for use in electrical machine calculations. This has been illustrated in the paper "Forces in Turbine Generator Stator Windings," by J. F. Calvert, AIEE TRANSACTIONS, March 1931, pages 178–94, and the scheme might have some value in this work of Professor Douglas' as well as in that for which it was used where the forces exerted on armature end windings were to be calculated.

J. F. H. Douglas: I quite agree with Mr. Alger's remark that considerable work is yet to be done. My paper is really more of a program for research, than anything else. It is gratifying to know that it seems to be a sound procedure.

Mr. Rosenberg's suggestion is interesting and of value. It is equivalent to assumption of a Rayleigh insulating plane perpendicular to the shaft at some point approximately 2–6 inches from the pole. Caldwell's method would be rigorously applicable outside this surface, my method could could be applied inside this surface. However no advantage is gained as yet. If immediate results are wanted Caldwell's formula is apparently the best to date. If greater accuracy is wished for the future why asume this plane at all? The assumption of a Rayleigh plane always decreases the answer, we would not know at present where to place it for best results, and we would still lack a usable formula for immediate use. The chief merit of this suggestion seems to me as a means of adapting theory to fit test results at some later date if it prove that Caldwell's formula is lower than test, and that my method gives reactances larger than test values.

Referring now to the careful analysis of Messrs. Calvert and Rohr, in the sequence of their numbered points.

1. Their suggestion of a current sheet appears decidedly superior to my rather crude semicircular fictitious conductor. It meets boundary conditions theoretically, and leads to an added item of permeance of 0.7 line per ampere turn for each inch of pole width (0.27 per centimeter). Their figures are particularly elegant and instructive.

2. Their point that the current sheet should divide in the ratio of 75 per cent and 25 per cent in a 4-pole machine is perhaps theoretically right for an isolated coil. However the simplest unit from which to build up inductance, is, perhaps, one coil for each pole, and for this case the distinction is unimportant.

3. I believe that the radial Rayleigh insulating planes should be intermediate between the pole-shoe tip and the edge of the pole core: (1) not much error is caused by assuming the outer end of the pole tip as insulating, (2) not much error is caused by assuming the narrow strip between this plane and the pole edge as conducting, (3) these errors compensate.

Their second point is whether a plane Rayleigh surface can be assumed with propriety at all. A Rayleigh surface always causes some error, but this error is small when in regions of highest density the lines are nearly parallel to the surface. In this case near the air gap the actual lines are parallel to this plane. Near the trace of the conductor they meet it at 40 degrees, It is believed therefore that some error is made but less than that of other methods proposed. By moving the Rayleigh plane toward the interpolar axis we eventually arrive at a point where it is obvious that the permeance is too large.

I conclude that by assuming the Rayleigh plane intermediate between the pole tip and the pole edge, but nearer the pole tip, we will get a balance between calculations and experiment.

4. In figure 5 the air gap should have been shown perhaps. However, if we assume armature ampere turns and balancing field ampere turns, we do not need any current sheet in the air gap, and have a basis for computing that part of the flux in the end zone, for 2 important cases, namely Potier reactance, and the inductance of commutation.

5. I believe these comments to be well founded, and helpful where housing iron needs to be considered.

6. The suggestions should be considered by future investigators. I believe them as more helpful in guiding tests than as an aid to calculations.

Hopes are expressed for a detailed discussion of how I propose to consider various phase groups in the end zone. A closing discussion is hardly the place for much detail and, to be frank, the writer is not going to take up the detailed solution at this time. Enough has been done since the paper was published, however, to show that Laplace's equation is easily integrable for coils that are 45-degree isosceles triangles both for self-induction, and for mutual induction between coils in the same and adjoining phase belts. The coil is the first unit, the phase belt is naturally the second, and the mutual inductance between phases and adjoining pole pitches naturally follow.

Approximating Potier Reactance

Discussion and author's closure of a paper by Sterling Beckwith presented at the power generation and electrical machinery session of the summer convention, Milwaukee, Wis., June 24, 1937, and published in the July 1937 issue, pages 813–18.

P. L. Alger: See discussion, page 1312.

S. B. Crary (General Electric Company, Schenectady, N. Y.): Mr. Beckwith's paper presents interesting data in regard to Potier reactance and methods of approximating it, which check with good accuracy a large number of test results. This information is valuable in that it increases our knowledge of machine reactances.

It is well to keep in mind that Potier reactance has only a limited field of usefulness, namely the approximate determination of field excitation for normal conditions of voltage and power factor. For any unusual conditions such as high terminal voltage or leading power factor or for the determination of the load angle and stability characteristics, the use of Potier reactance determined at normal voltage may give results which are too approximate. There appears to be no real reason for using Potier reactance for design computations as in such work all the machine quantities are available and the field excitation can be calculated by more accurate methods. For those cases other than for design computations Potier reactance can usually be determined by test.

The method which Beckwith has used for determining the pole saturation, by adding the transient reactance drop to terminal voltage to obtain the pole flux, can only be used for the condition of zero power factor, which is the condition for determining Potier reactance. For other power factors, if the approach is made from the armature, it would be necessary to add to the direct-axis component of terminal voltage the direct-axis component of transient reactance voltage drop. In order to determine these direct-axis components, it is necessary to know that component of saturation-magnetomotive force which is a function of the quadrature-axis flux, as saturation in the quadrature axis affects the machine angular displacement. These complications are to a considerable extent the reason for the use of Potier reactance for excitation calculations, as it provides a method which has been found to give approximately the correct excitation by a comparatively simple calculation. However, the use of Potier reactance does not give the proper load angle of the machine and in some cases does not give the correct excitation. The greatest disadvantage for its use is that it tends to conceal the true physical picture.

G. W. Hampe (Commonwealth Edison Company, Chicago, Ill.): The writer is pleased to see that the constants of synchronous machines are being subjected to careful analysis, both in regard to furnishing sound concepts and in development of methods of computation and test. As one who makes computations for systems containing synchronous machines, the writer can say that such studies are needed, and that the results should be made available to all who can make effective use of them.

If it is granted, for the present, that the primary concepts have been defined and methods of computation and test have been made available, what is the resulting advantage to the operating engineer? Manufacturing companies have always willingly furnished data on their machines, both old and new. Likewise, power companies have freely given information to their interconnected associates. Unfortunately, however, these communications have been haphazard and occasionally repetitive.

The writer suggests that a standard form or set of forms be developed so that all data pertinent to the electrical properties of a given machine can be recorded on one sheet. Part of the data for such a form, such as the reactances, would usually be supplied by the manufacturer, and the balance, referring to external reactors, field rheostats, etc., would be filled in by the operating company. The writer would like to call this matter to the attention of the AIEE committee on synchronous machinery.

Such a form should *not* be made up with a view of obliging each manufacturer to compile all the data for every machine, large and small. When data are furnished, however, they should follow the standard definitions accepted, at that time, and the use of a standard form would systematize communications.

The papers, particularly the one by Mr. Beckwith, added to the rather scanty stock of published test data. More data are needed in regard to machine constants in general, particularly for large machines. As an example of this need, Mr. Beckwith offered an approximate formula relating Potier reactance to unsaturated transient reactance, which brings up the question of saturation. In the AIEE summer convention in 1931, Mr. S. H. Wright stated that the saturated transient reactance x_d' was related to the unsaturated value by the formula:

$$x_d' \text{ (sat.)} = 0.88\, x_d' \text{ (unsat.)}$$

This formula was questioned, but to date the writer has not seen a satisfactory alternative. In some types of power system computations both the saturated and unsaturated values are needed, and usually one must be derived from the other by a formula of some sort.

The test methods known at present are not applied for several reasons. The manufacturer seldom has facilities for testing a large machine before shipment. The operating company could make the test, but it means trouble and expense, not only for the testing setup itself but because the machine may be badly needed on the system. A large part of the cost is hidden and indirect. Furthermore the operating company probably has only one machine of that class, and a refinement in data means little because of its limited applicability. The same expenditure for a test of system stability or relay performance yields data of greater value.

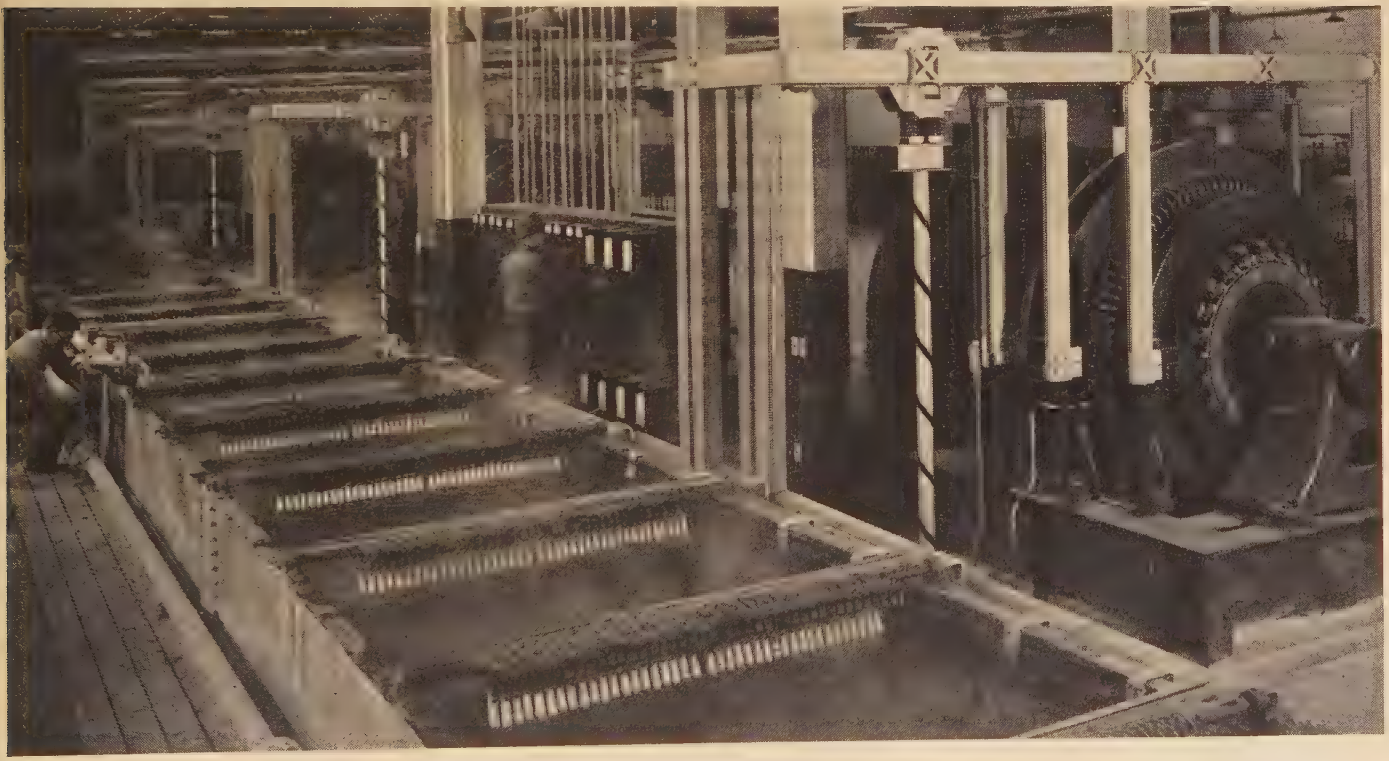
The manufacturer can profit by tests on individual machines, because he is concerned with a number of machines of the same class, and, furthermore, there should be occasional checks on general methods of computation and design. It would seem then that the manufacturer should co-operate more frequently with the operating company in securing test data, and it would seem that the manufacturer should share the costs.

Sterling Beckwith: Mr. Crary's comment that the use of Potier reactance tends to obscure the exact picture is quite correct, and should be borne in mind when using the reactance. However, a clearer picture of the magnitude and range of the reactance and its relation to other reactances should have the opposite effect. Mr. Crary limits the use of Potier reactance to the calculation of field currents, but a further use is for determining the effects of saturation on stability.

Although Potier reactance varies with current and voltage, it should be pointed out that most synchronous-machine reactances are subject to the same variation. Furthermore Potier reactance is subject to easier and more accurate test than are most reactances.

Mr. Hampe raises the question of saturation of transient reactance. The curve mentioned showing an average value of saturated reactance equal to 88 per cent of the unsaturated value does not take terminal voltage into account. Thus when the internal voltage is above normal the saturation factor may be much lower than 88 per cent. Tests with which the writer is familiar indicate that an average value is 83 per cent to 88 per cent for a dead short circuit at rated voltage, but that it may vary very greatly in different machines.

Perhaps Mr. Hampe's suggestion of a standard form for machine characteristics might be filled to some extent by references to the "Proposed Test Code for Synchronous Machines." One advantage of references to such a test code is that definitions are usually definite and unambiguous, whereas any abbreviated form might lack this advantage. A summary sheet added to the test code might make it more suitable for the purpose.



Steel wire is electrogalvanized in the new Chicago, Ill., plant of the Republic Steel Corporation by current from 4 15,000-ampere d-c generators. The current is distributed to 27 sets of porcelain-insulated fingers which make contact with 40 strands of wire that pass continuously through the 140-foot electrolytic bath at speeds from 35 to 70 feet per minute. Thickness of the zinc coating is controlled by speed of wire travel and current density. Electrogalvanizing produces a coating that is considered superior to hot galvanizing because of its better adherence, greater uniformity, and purity, but difficulties of cleaning and deposition, solved only recently, retarded development

News
Of Institute and Related Activities

Pacific Coast Holds Successful Convention at Spokane

TWO hundred and sixty-six members and guests enjoyed the 25th Pacific Coast convention, which was held at Spokane, Wash., with headquarters in the Hotel Davenport, from Tuesday morning through Friday, August 31–September 3, 1937. On the part of those in attendance full advantage was taken of the technical sessions, student sessions, entertainment, sports, and inspection trips, which had been well arranged by the convention committee, and many were afforded the opportunity of meeting old acquaintances.

The opening session on Tuesday morning was called to order by Dean H. V. Carpenter, convention chairman, who introduced Arthur W. Burch, mayor of Spokane. The mayor welcomed to the city those attending the convention and he advised that Frank G. Sutherlin, commissioner of public utilities, would be delighted to have members inspect the electric plant up the river.

President Harrison expressed appreciation on behalf of the Institute of the welcome extended by Mayor Burch, who had been ill but came down to greet the assemblage on his second day out. He complimented the District and Section officers upon the favorable manner in which the conventions, student activities, and student prizes have been conducted on the Pacific Coast. At the conclusion of the opening of the convention R. W. Sorensen proceeded with the conduct of the selected subjects session.

Technical Sessions

A keen interest on the part of those who attended the 6 technical sessions and 2 student sessions was maintained throughout the duration of each session. One of the 6 technical sessions, which dealt informally with the subject of electric house heating, was held on Wednesday evening with Professor F. O. McMillan presiding. Doctor C. E. Magnusson, director of the Engineering Experiment Station, University of Washington, presented a summary and recommendations of the investigation on the electric heating of homes in the Mont Lake district of Seattle. The work was originally done for the State Planning Council. The complete report of this work, with results and conclusions, is available in Bulletin No. 93, "Electric Power Markets in Washington—Part I, Electric Heating of Residences," recently published by the Engineering Experiment Station, University of Washington. Dean H. V. Carpenter of the State College of Washington, presented a paper on the same subject, which reported the results of experiments on different methods of heat storage for electrically heating the specially constructed and insulated houses at Mason City. These papers were discussed by several well-known executives and engineers of operating companies in the Pacific northwest, who found the studies to be most valuable but not in agreement with the practical problems of power distribution, as experienced in operating company work. Another session, on the subject of communication, which was held jointly with the members attending the Institute of Radio Engineers' meeting, was well attended and considerable interest was manifested in the 6 papers which were presented.

Most of the convention papers were personally presented by their respective authors, and, in cases where the authors were unable to attend, comprehensive and effective presentations were made by F. C. Lindvall, California Institute of Technology, P. B. Garrett, Westinghouse Electric & Manufacturing Company, H. H. Skilling, Stanford University, W. C. Smith, General Electric Company, and S. B. Wright, Bell Telephone Laboratories, Inc.

Student Technical Sessions

In accordance with the practice followed for a considerable number of years, 2 student technical sessions were held as parts of the convention technical program. Eleven papers, as listed below, were presented:

Wednesday Afternoon

J. S. Mascovich, chairman, University of Santa Clara Branch, presiding.

Balanced Feed-Back Amplifiers, Edward L. Gintzton, University of California

A Method of Measuring Losses in Small Transformers, Bruce Morgan, California Institute of Technology

Laboratory Equipment for Construction of Experimental Electron Tubes, H. P. Blanchard, Stanford University (presented by Leonard M. Jeffers, Jr., chairman, Stanford University Branch)

Magnetic Focusing of the Electron Gun, L. Dale Harris, University of Utah (presented by William R. Wilson, chairman, University of Utah Branch)

Influence of Utensils on Heat Transfer from Electric Range Elements, William G. Short, Oregon State College

Thursday Afternoon

Gordon B. Allan, chairman, Montana State College Branch, presiding.

A High Impedance Detector Circuit With a Diode, John W. Stoker, Jr., Montana State College

Torque in Induction Disk Instruments, G. I. Goumeniouk, University of British Columbia

Variable Gain Amplifier and Its Application, J. F. Kalbach, University of Washington (presented by Rush Chase, University of Washington '37)

Electrostatic Air Purification, W. D. Arms, University of Idaho (presented by W. T. Connely, University of Idaho, February '37)

Measurement of the Field Strength of Radio Station KWSC, William Lean, State College of Washington

Characteristics of A-C Welding, O. C. Bixler, University of Southern California (presented by A. E. Harrald, chairman, University of Southern California Branch)

The quality of the presentations was high despite the facts that several authors were absent and their papers were presented by students and recent graduates not directly connected with the work discussed. The subject matter of all maintained a high degree of interest throughout the 2 sessions and some of the papers were discussed by students and others.

Conference on Student Activities

A joint conference on student activities for representatives of the student Branches in Districts 8 and 9, and the University of British Columbia Branch, as well as District officers and others interested, was held at a dinner meeting on Wednesday evening, with an attendance of 38, as reported in more detail below:

Branch Chairmen

John Draper, University of Arizona, Tucson
Bruce Morgan, California Institute of Technology, Pasadena
Peter Duyan, University of California, Berkeley
Gordon B. Allan, Montana State College, Bozeman
Guy K. Patterson, University of Nevada, Reno
Victor S. Carson, Oregon State College, Corvallis
J. S. Mascovich, University of Santa Clara, Santa Clara, Calif.
Leonard M. Jeffers, Jr., Stanford University, Calif.
William R. Wilson, University of Utah, Salt Lake City

Counselors

W. B. Coulthard, University of British Columbia, Vancouver
F. C. Lindvall, California Institute of Technology, Pasadena
Abe Tilles, University of California, Berkeley
J. H. Johnson, University of Idaho, Moscow
A. L. Albert, Oregon State College, Corvallis
W. G. Angermann, University of Southern California, Los Angeles
E. F. Peterson, University of Santa Clara, Santa Clara, Calif., and chairman, committee on Student activities, District 8
H. H. Skilling, Stanford University, Stanford University, Calif.
A. LeRoy Taylor, University of Utah, Salt Lake City
O. E. Osburn, State College of Washington, Pullman
R. E. Lindblom, University of Washington, Seattle

Others Present

J. P. Jollyman, vice-president, District 8
A. M. Bohnert, secretary, District 8
C. E. Rogers, vice-president, District 9
S. E. Caldwell, secretary, District 9
F. Ellis Johnson, director, and chairman, committee on student Branches
E. A. Loew, member, committee on student Branches
R. W. Sorensen, director, and member, committee on student Branches
H. V. Carpenter, chairman, Pacific Coast convention committee
R. H. Hull, chairman, student activities subcommittee, Pacific Coast convention committee
H. H. Henline, national secretary, and several professors, students, and others as guests—total 38

Analysis of Attendance at 1937 Pacific Coast Convention

Classification	Spokane	Dist. 9*	Dist. 8	Dist. 10	Misc.	Totals
Members	28	35	25	5	15	108
Men Guests	22	43	23	2	7	97
Women Guests	20	20	16	1	4	61
Totals	70	98	64	8	26	266

* Outside of Spokane Section territory.

Professor E. F. Peterson of the University of Santa Clara, chairman of the committee on student activities in District 8, presided, and presented as the first item for consideration a list of suggestions for the guidance of counselors in Districts 8 and 9 which had been prepared by a committee including all counselors in Districts 8 and 9, with Professor Peterson as chairman. After an extensive discussion of the individual suggestions, the committee was given a vote of thanks and requested to continue the work and report again at the next conference.

It was voted to recommend that the board of directors consider the possibility of reestablishing the cash prize of $100 for the best Branch paper prize.

Many of those present expressed strong hope that such a joint conference, with traveling expense allowance to official representatives, may be provided for regularly so it will not be necessary to request special action each year. There was some discussion of the best time for such conference from the standpoint of attendance by students.

Vice-presidents Jollyman and Rogers, Directors Johnson and Sorensen, chairman and member, respectively, of committee on student Branches, Professor E. A. Loew, member of that committee, and National Secretary Henline were called upon for brief remarks, and all responded, giving information and opinions regarding various phases of student activities in the Institute.

After the adjournment of the conference, the counselors of the 2 Districts met in separate groups and elected as chairmen of the District committees on student activities:

Pacific District (Number 8)—Professor H. H. Skilling, Stanford University
North West District (Number 9)—Professor A. LeRoy Taylor, University of Utah

Entertainment

On Tuesday evening a number of members and guests enjoyed an informal reception and dancing held in the Marie Antoinette Room of the Davenport Hotel. The entertainment concluded with the banquet and presentation of sports prizes, which took place on Thursday evening and which was well attended. Splendid entertainment in the form of aesthetic dancing, singing, and music rendered by the Mann Brothers orchestra was furnished. Toastmaster J. E. E. Royer, vice-president and general manager of the Washington Water Power Company, conducted the banquet in true social fashion by admonishing those in attendance "to forget their kilowatt words" and enjoy themselves. President W. H. Harrison of the AIEE and President H. H. Beverage of the IRE greeted the guests.

Presentation of Sports Prizes

The sports prizes were presented in person by the well-known pioneer in hydroelectric developments in the northwest, John B. Fisken. The competition for the Fisken cup resulted in a tie between C. E. Boozier, Portland, C. H. Cutter, Seattle, and R. H. Dearborn, Corvallis, which was decided by the rolling of dice. Dean Dearborn won the trophy with C. C. Boozier runner-up. W. E. Wallace, Seattle, won the guests' competition with J. F. Gogins, Spokane, runner-up. Prizes were presented for the remaining events open to both members and guests: low gross, J. C. Henkle, Portland; longest drive at hole number 3, M. P. Buswell, Seattle; approach nearest pin at holes numbers 9 and 17, J. C. Henkel and H. A. Boring, Seattle; kickers handicap, L. R. Elder, Portland; and high gross, C. B. Carpenter, Portland. Birdies were scored by J. E. E. Royer, J. W. Butler, Schenectady, J. C. Henkle, M. P. Buswell, and J. W. Ferguson, Seattle. The women's putting contest was won by Mrs. W. H. Ude, Spokane, with Mrs. Chet Reis, runner-up. First prize for approach was won by Mrs. M. M. Phegley, Glendale, Calif., and second prize was won by Mrs. H. B. Hodgins, Spokane. The winners of consecutive flights were respectively as follows: Mrs. J. H. Siegfried, Kennewick, Mrs. C. E. Rogers, Seattle, Mrs. M. M. Phegley, Mrs. S. B. Wright, South Orange, N. J., Mrs. J. C. Bird, Seattle, Mrs. A. C. Schwager, San Francisco, Calif. Mrs. R. W. Sorensen, Pasadena, and Mrs. A. H. Beckwith, Spokane. Excellent prizes consisting of leather luggage, golf clubs, a silver platter, golf balls, and favors were made possible through the courtesy and financial support of several manufacturing and operating companies in the Pacific Coast region.

Women's Entertainment

Under the guidance of Mrs. L. R. Gamble, Seattle, chairman, women's entertainment committee, a pleasant series of events was arranged. Tuesday morning the women got together for the purpose of becoming acquainted with one another, after which the group divided; one group took a drive about the city and gardens, while the other attended the "movies" at the Fox Theater. Luncheon was held in the Elizabeth Rooms of the Hotel Davenport. On Wednesday morning shopping tours were conducted and a bridge-luncheon was held at Glen Tana. Winners of prizes were Mrs. J. F. Spease, Portland, Mrs. C. C. Boozier, Portland, Mrs. Charles North, Kamloops, B. C., Canada, and Mrs. J. H. Neher, Philadelphia, Pa. Mrs. J. C. Bird of Seattle won the auction. One of the prizes consisted of a jar of herbs obtained from the beautiful gardens at Glen Tana. Thursday the principal event consisted of a scenic drive through the residential districts and civic gardens of Spokane, which was followed by a putting tournament and tea at the Spokane Country Club and a musical hour with selections rendered on the harp and cello.

Trips

The principal trip was held on Friday, when over 250 members and guests of the AIEE and the IRE left the Hotel Davenport by bus and private car at 8:00 a.m. to see the Grand Coulee Dam, now in process of construction. Addresses on the features of the project were given by A. F. Darland, C. D. Riddle, and Mr. Banks, and a model of the dam was seen in the West Vista House. Luncheon was served in the contractor's mess hall on the east side of the river. The return to Spokane was made via Grand Coulee, and Dry Falls where the Columbia River once outrivalled the Niagara.

During the convention, trips were taken in private cars to various points of interest in Spokane and vicinity. Among the places visited were the Up-River Hydroelectric

Membership—

Mr. Institute Member:

AIEE meetings and other activities get under way about this time of the year in many Sections.

I hope you will plan to get the most out of your Institute connections this season by attending what conventions, Section meetings, and other affairs you can, and by taking an active part in them in some way.

You may also be able to assist a nonmember friend by taking him with you and by introducing him to other members. If he becomes interested and is eligible for membership your membership committee will help him in making his application. Just write to your Section membership chairman or to headquarters.

L. L. Webb

Assistant Chairman
National Membership Committee

Station of the water department, the Ray and Hartson Pumping Plant, the radio tower of KHQ-KGA, and the Inland Paper Company mill, as well as the beautiful residential section and gardens in the city.

The personnel of the committee and the subcommittee chairmen which made all of the foregoing events possible is as follows: H. V. Carpenter, chairman; R. D. Sloan, vice chairman; M. F. Hatch, secretary; Reinier Beeuwkes, S. E. Caldwell, J. B. Fisken, L. R. Gamble, J. C. Gaylord, C. R. Higson, N. B. Hinson, R. H. Hull, H. S. Lane, F. O. McMillan, H. L. Melvin, H. S. Osborne, George Quinan, C. E. Rogers, R. W. Sorensen, and A. Vilstrup: L. R. Gamble, meetings and papers; J. S. McNair, finance; L. A. Traub, transportation; H. W. Webbe, housing; J. R. Murphy, entertainment; J. B. Fisken, sports; H. B. Hodgins, publicity; R. H. Hull, student activities; D. H. Olney, registration; Earl Baughn, inspection trips; and Mrs. L. R. Gamble, women's entertainment.

AIEE Board of Directors Meets at Institute Headquarters

THE regular meeting of the AIEE board of directors was held at Institute headquarters, New York, August 3, 1937.

Present: *President*—W. H. Harrison, New York, N. Y. *Past-President*—A. M. MacCutcheon, Cleveland, Ohio. *Vice-Presidents*—O. B. Blackwell, New York, N. Y.; C. Francis Harding, Lafayette, Ind.; I. Melville Stein, Philadelphia, Pa.; A. C. Stevens, Schenectady, N. Y. *Directors*—C. R. Beardsley, Brooklyn, N. Y.; F. M. Farmer, New York, N. Y.; F. Ellis Johnson, Columbia, Mo.; C. R. Jones, New York, N. Y.; W. B. Kouwenhoven, Baltimore, Md.; K. B. McEachron, Pittsfield, Mass. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

Minutes of the meeting of the board of directors held June 24, 1937, were approved.

Report was presented and approved of recommendations adopted by the board of examiners at its meeting held July 21, 1937. Upon the recommendation of the board of examiners, the following actions were taken: 3 applicants were transferred to the grade of Fellow; 29 applicants were elected and 35 were transferred to the grade of Member; 124 applicants were elected to the grade of Associate; 20 Students were enrolled.

Disbursements in July amounting to $27,618.84 were reported by the finance committee and approved.

Approval was given to a proposed meeting of the Southern District in Miami, Fla., in November 1938.

Announcement was made of the appointment by the president of Institute committees for the new administrative year, beginning August 1, 1937. (A list of committee members was published in Electrical Engineering for September, pages 1217–21.)

The board confirmed the appointment by the president of H. P. Charlesworth as chairman of the Edison Medal committee for the year beginning August 1, 1937, and of C. R. Jones, Everett S. Lee, and H. S. Osborne as members of the committee for terms of 5 years each beginning August 1, 1937, and of L. W. W. Morrow to serve for the unexpired term, ending July 31, 1939, of L. C. Nichols, deceased. From its own membership, the board elected C. R. Beardsley, A. M. MacCutcheon, and K. B. McEachron to serve on the committee for terms of 2 years each, beginning August 1, 1937.

The board confirmed the appointment by the president of F. J. Chesterman, C. F. Hirshfeld, and A. H. Kehoe as members of the Lamme Medal committee for terms of 3 years each, beginning August 1, 1937.

It was decided to discontinue the Advisory Committee to the New York Museum of Science and Industry, as there appeared to be no further need for this committee, the museum having become well established on a definite basis.

Representatives of the Institute on various bodies were appointed for the year beginning August 1, 1937, and the appointment of certain representatives was deferred until further information could be obtained regarding the activities of the organizations, the necessity for continued representation thereon, or concerning suitable individuals for appointment.

W. I. Slichter was reappointed a representative of the Institute on the Library Board of the United Engineering Trustees, Inc., for the 4-year term beginning in October 1937; and L. W. Chubb was nominated for reappointment by The Engineering Foundation board to the research procedure committee of Foundation, for the term of one year beginning in October 1937. J. B. Whitehead, past-president of the Institute, was appointed to fill the unexpired term, ending in October 1939, of E. B. Meyer, deceased, on the John Fritz Medal Board of Award.

Local honorary secretaries were reappointed for the term of 2 years, beginning August 1, 1937, as follows: Frederick M. Servos, for Brazil; A. P. M. Fleming, for England; Renzo Norsa, for Italy; P. H. Powell, for New Zealand; A. F. Enstrom, for Sweden.

The following amendments to the by-laws were adopted:

Section 32, to include the District vice-chairmen of the membership committee, amended to read as follows:

> Sec. 32. To facilitate co-operation among the Sections there shall be an executive committee in each geographical district, including in its membership the vice-president representing the District on the board of directors, as chairman, a District secretary to be appointed by the vice-president, as secretary, the vice-chairman of the national membership committee, who may be a member of the District executive committee in another capacity also, and the chairmen and secretaries of the Sections within the District; also, in order to encourage co-operation between Sections and Branches, the chairman of the District committee on student activities.

Section 41 was amended to read as follows, in order to define the boundaries of Sections, which were recently revised in accordance with recommendations of the special committee to revise Section territories:

> Sec. 41. Unless otherwise authorized by the board of directors and approved by the Sections and finance committees, the territory of a Section shall be defined as follows: A Section shall include those counties lying wholly or partly within a circle having its center at the headquarters of the Section and a radius of 50 miles. With the additional approval of the vice-president of the District involved, other unassigned counties, to be known as auxiliary Section territory, may be assigned to a Section. If, for the purpose of establishing a new Section, or for any other reason, it becomes desirable to reassign counties in auxiliary Section territory, this may be done without the approval of the Section to which such auxiliary territory is assigned, provided the change meets with the approval of the Sections committee and the vice-president of the District. All other questions with regard to overlapping of Section territories shall, if possible, be decided by agreement by the Sections concerned, otherwise by the Sections committee. Both ordinary and auxiliary Section territories shall be defined by county line boundaries.

Section 65 was amended by the substitution of the name "committee on basic sciences" for "committee on electrophysics."

Section 76 was amended to read as follows:

> Sec. 76. The membership committee shall consist of one vice-chairman from each geographical district and a suitable number of other members, all to be appointed by the president; also the chairmen of the membership committees of the Sections of the Institute, *ex-officio*.
>
> This committee shall bring the advantages of membership to the attention of desirable candidates for admission to the Institute, through such measures as it may consider advisable to interest prospective members who have the standing and qualifications specified for the various grades of membership. Under the general direction of the chairman, the vice-chairman may enlist the co-operation of the Sections and Branches within his District in such work. The committee shall have such other duties as may be delegated to it by the board of directors.

The following appointments by the standards committee of Institute representatives on subcommittees of the Sectional Committee for Revision of National Electrical Safety Code were approved: W. R. Bullard—Grounding; C. A. Powel—Part I; T. H. Haines—Part II; E. B. Paxton—Part III; S. B. Graham—Part V.

Upon the recommendation of the standards committee, approval was given to (1) Revised Code for Protection Against Lightning, developed by the sectional committee *C*-5 under ASA procedure, and (2) Revised Test Code for Polyphase Induction Machines.

An invitation to nominate an individual for the award of the 1938 Kelvin Medal was referred to a committee consisting of the president of the Institute and the chairmen of the Edison Medal and Lamme Medal committees to make a nomination.

The report of the special committee on Institute activities, on which action was deferred at the June meeting of the board of directors, was considered. The committee reported that, in accordance with instructions, it had prepared a general session at the 1938 summer convention of the Institute, which consisted of an address by Ralph E. Flanders on "The Engineer in a Changing World," followed by questions from the floor, and, after intermission, a discussion by members of the Institute on the topic "How Can the Institute Programs be Made of Greatest Value to the Membership?" This discussion was opened by 6 prepared discussions which had been reviewed by the special committee, and which presented various points of view (published in August issue of Electrical Engineering, pages

1054–58). As a result of this session, the special committee recommended, in brief, that major emphasis should continue to be given to the technical programs substantially along the present lines; that the programs of national conventions and District meetings of the Institute frequently include sessions at which subjects of general interest to all the membership are discussed, including broad technical subjects presented in such a form as to be of general interest to electrical engineers, and also discussions of social and economic subjects closely related to engineering, which subjects should be presented by authorities in the fields discussed, and, in many cases therefore, would take the form of addresses by men who are not members of the Institute; and that the inclusion or omission of such a general session in the case of each convention or meeting be decided by the committee in charge of the program of that convention or meeting. The board approved the report of the special committee on Institute activities.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Additional Awards for 1936 Institute Papers

In addition to the national and District prize awards for papers presented before the Institute during 1936 announced in ELECTRICAL ENGINEERING for June 1937, page 756, and September 1937, page 1208, additional awards for District 8 have now been announced. These awards are:

DISTRICT 8

Prize for Branch paper awarded to James W. McRae for his paper "The Magnetic Vector Potential," presented at the summer convention, Pasadena, Calif., June 22–26, 1936.

Prize for graduate student paper awarded to Edward L. Ginzton for his paper "Balanced Feed Back Amplifiers," presented at meeting of University of California Branch, April 1937.

Sodium Lights for Railroad Crossings

General Electric Photo

THE Ohio Public Utilities Commission has approved the use of sodium lights for railroad crossing illumination. In the accompanying illustration is shown a typical installation of 2 sodium luminaires at the point where route 40 crosses the tracks of the Cleveland, Cincinnati, Chicago, and St. Louis Railroad.

New System of Photometric Units

THE International Committee on Weights and Measures at its biennial meeting in Paris, June 23–29, 1937, adopted a new system of photometric units intended to replace both the "international" and the Hefner units. The following report on this action has been made available by E. C. Crittenden (A'19, M'22) assistant director, National Bureau of Standards, Washington, D. C., who has been closely associated with the development. This action of the international committee is expressed in a resolution translated as follows:

1. Beginning January 1, 1940, the unit of luminous intensity shall be such that the brightness of the black-body radiator at the temperature of solidification of platinum will be 60 candles per square centimeter.

This unit will be called the "new candle," ("bougie nouvelle") with appropriate translation into the various languages.

2*a*. The values for photometric magnitudes of sources of light differing in color from the primary standard shall be determined by a procedure consistent with the luminosity factors, formerly called "visibility factors," adopted by the International Committee on Weights and Measures.

2*b*. To assure uniformity among the national laboratories of the different countries in passing from the new primary standard to secondary standards of the incandescent-filament type operating at higher efficiency, the procedure adopted for the present is the use of blue filters which, interposed between the photometer and one of the standards to be compared, will make the colors in the 2 parts of the photometric field the same.

The international bodies concerned had previously agreed, first, that the use of the luminosity or "visibility" factors adopted by the Illuminating Engineering Society and the AIEE was the only method of hetochromatic photometry which could be generally accepted; and, second, that the primary standard of light should be the black body at the platinum point. In order to fix the values of all the units, it remained only to agree upon a numerical value for the brightness of the primary black-body standard.

The freezing point of platinum, 2,046 degrees Kelvin, is only about 50 degrees below the color temperature of the old carbon-filament standards; the black-body standard therefore might have been considered simply as a reproducible means of representing the international candle at that color. However, if this had been done, several very troublesome questions would have been left unsettled.

While nominally only 2 units of candlepower are in use today, actually there are several units differing enough to cause annoyance in the lamp industry. The ratings of tungsten-filament lamps, first of vacuum type and later gas-filled, have been established without any specific international agreement. Consequently there are slight, but systematic, differences between different countries which use "international" candles or lumens, and still greater discrepancies exist between the international and the Hefner units as established for the 3 general types of lamps. For carbon lamps the ratio between the 2 units accepted in 1909 was 1.11; for vacuum tungsten lamps at color temperatures near 2,360 degrees Kelvin it is 1.45; for gas-filled lamps in the neighborhood of 2,600 degrees Kelvin it is 1.17.

Furthermore, if the old basic units were retained both international and Hefner ratings of tungsten lamps would have to be changed to bring them into accordance with recent agreements regarding photometric methods to be used in comparing lights of

Future AIEE Meetings

Middle Eastern District Meeting
Akron, Ohio, Oct. 13–15, 1937

Winter Convention
New York, N. Y., January 24–28, 1938

North Eastern District Meeting
Pittsfield, Mass., Spring 1938

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., date to be determined

different colors. Most of the present tungsten standards were derived from the carbon-filament standards representing the international candle of 1909 by measurements with the common Lummer-Brodhun photometer, which has a fairly large field of view. For nearly all groups of observers this gives somewhat larger values for the bluer lights than are obtained with a small photometric field such as was used in determining the standard "visibility factors."

In brief, in order to get the ratings of tungsten-filament lamps on a consistent and systematic basis, some readjustment is necessary in all countries. Such a basis is now urgently needed also for the precise rating of gaseous conductor lamps and other sources of colored light. Consequently, when a new standard was to be adopted as a means of defining the basic unit, the time seemed opportune to make an adjustment which might bring all countries into agreement.

Determinations of the brightness of the black body at the platinum point in terms of the international candle had been made in several countries, and the value on this basis was about 58.9 candles per square centimeter. The National Bureau of Standards proposed that the round number 60 be taken for the brightness, making the unit at this color 1.8 per cent smaller than the old unit.

In preliminary discussions in 1935 and 1936 it was indicated that, if the countries which used the international candle abandoned it for the proposed new unit, Germany was ready also to accept the new unit in place of the Hefner. The plan therefore was put formally before the International Committee on Weights and Measures as a joint proposal of the national laboratories of France, Great Britain, and the United States, which have had the responsibility of maintaining the international candle.

At the same time the plan was submitted to the International Commission on Illumination, which asked the views of all its national committees. In order to determine the opinion of American interests, Preston S. Millar, president of the United States national committee of the ICI, formed a special subcommittee including representatives of all the national organizations specially concerned.

At a meeting held February 5, 1937, this subcommittee unanimously favored the proposal, and consequently the United States national committee gave its approval. During June, meetings were held in Paris by the special committee on units and standards of the ICI and by the advisory committee on photometry established by the International Committee on Weights and Measures. These meetings settled questions of detail and cleared the way for definite action by the international committee.

While the action of the international committee establishes the principle of the new system, the determination of precise values for standards of the various types will require considerable time. Determinations in different laboratories will be necessary, and standard lamps of various types must be exchanged between countries for comparisons so as to make sure that all the national standardizing laboratories are in satisfactory agreement. Standards on the new basis must then be provided for lamp factories and testing laboratories in each country.

Some of this necessary laboratory work is already in progress, but it is hardly likely that all the measurements and all the formalities of final agreement can be completed in less than 2 years. The effective data of January 1, 1940, was set with this fact in mind. It also has the advantage of making the photometric changes coincide with a small adjustment of electrical units which is scheduled for the same date.

NRC Insulation Committee to Meet in New York

The fall meetng of the committee on electrical insulation of the division of engineering and industrial research of the National Research Council will be held in New York, N. Y., November 4–5, 1937, with the Consolidated Edison Company of New York, Inc., as host. W. F. Davidson (A'14, F'26) director of research and tests, of the Edison company, is chairman of the committee on arrangements.

A program including 16 papers to be presented at 3 sessions has been arranged; fewer papers than usual have been scheduled this year in order to allow more time for discussion. Morning and afternoon sessions will be held November 4, and a morning session November 5; all 3 sessions will be held in the auditorium of the Edison company at 4 Irving Place. Inspection trips to nearby points of interest are being arranged for the afternoon of November 5. A dinner meeting is scheduled for the evening of November 4 at which Doctor A. von Hippel of the Massachusetts Institute of Technology, Cambridge, will speak on the subject "What Can Atom Physics Contribute to Insulation Research?"

New ASTM Standards. At its recent annual meeting the American Society for Testing Materials accepted 51 new tentative standards and revisions of 46 existing tentative specifications and methods of test. Among these were the following, covering methods of testing electrical insulating materials:

1. TEST FOR INSULATION RESISTANCE OF ELECTRICAL INSULATING MATERIALS (D 257–37 T) (REVISION OF STANDARD). Committee D–9 on electrical insulating materials.

2. TESTING FLEXIBLE VARNISHED TUBING USED FOR ELECTRICAL INSULATION (D 350–37 T). Committee D–9.

Coffin Award for New York Company. The Consolidated Edison Company of New York, Inc., won the annual award for 1936 of the Charles A. Coffin Foundation, established by the General Electric Company. Presentation of the award was made to J. C. Parker (A'04, F'12) vice-president of the company, during the recent annual convention of the Edison Electric Institute. The award comprises the Charles A. Coffin Gold Medal, a certificate, and a check for $1,000 to be deposited in the treasury of the Consolidated Edison Employees Mutual Aid Society, Inc. Determination of the winner of the award was made by a committee of judges consisting of C. W. Kellogg (A'19, M'23) president of EEI; K. T. Compton (F'31) president of Massachusetts Institute of Technology; and L. H. Egan (A'08, M'15) president of the Union Electric Light and Power Company of St. Louis, Mo. The committee was particularly impressed with the all-around progress made by the utility during recent years, culminating in its splendid accomplishments for the year 1936. Progress was reflected in practically all fields of activity, including improvement of relations with consumers, refunding of bonds, reorganization of units, and the development of greatly improved generating and distribution facilities.

1939 Fairs to Have Electrified Farms

Electrified farms, complete in all details according to recent announcements, are to be among the feature displays of the Golden Gate International Exposition and the New York World's Fair in 1939. With an estimated 1,118,000 farms in the United States all served with electric power, these exhibits are expected to have wide significance in their demonstration of the possibilities of efficient and effective utilization of electric energy in house, barn, dairy, shop, and field.

As announced, the demonstration farm at the New York Fair will comprise some 32,400 square feet. To assure that the farm will be in full and effective operation when the Fair opens, it is expected that the building will be completed; that dairy cattle, poultry, and bees will be in their places; that crops will be growing and fruit trees will have been established before the Fair opens.

The exhibit at the Golden Gate Exposition will be in the Palace of Electricity, where a model farm, completely electrified for operations from dishwashing to forced crop production, will include demonstrations of protection against insect and walnut and prune dehydrators.

ICI Conference Held in Paris

On the occasion of the Paris Exposition and the attendant International Congress on Lighting Applications, a conference of delegates of International Commission on Illumination national committees was held June 22 and 23, 1937, to recommend plans for the forthcoming plenary session. Twenty-five delegates from 11 countries were in attendance, the United States being represented by C. H. Sharp (A'02, F'12, member for life), E. C. Crittenden, (A'19, M'22), and A. L. Powell (A'13, F'26).

The conference recommended that the program of the plenary session be expanded to include papers on latest lighting developments. To facilitate this and allow a longer interval after the Paris Congress, it was recommended that the sessions be postponed until 1939. The Netherlands committee, host of these sessions, announced that they would probably be held at the attractive Scheveningen seashore resort in the outskirts of The Hague.

In the event of postponement it was suggested that interim meetings be held on aviation and automobile lighting. In this connection it was reported that the International Standards Association had laid out an extensive program of automobile standardization, including that of lighting equipment.

It was expected that the *Proceedings* of the 1935 sessions, which have been delayed in publication, will be available early this fall. A pamphlet, in French, has been made available which gives the recommendations officially adopted by the International Commission on Illumination in the 1935 sessions in Germany. A list of the technical committees with the work assigned to each also is included. Requests for copies should be addressed to G. H. Stickney, secretary-treasurer of the United States National Committee of ICI, General Electric Company, Nela Park, Cleveland, Ohio.

Current Items From American Engineering Council

Government Reorganization

Government reorganization, including all of the ideas advanced for a public works department, was left in the muchly tangled mass of unfinished business by the first session of the 75th Congress, according to a recent "news letter" from AEC. It had the President's blessing, but the advantages to be gained by the elimination of duplication of work and the improvements proposed for administrative procedure were handicapped by moves to effect radical changes in fiscal and personnel administration and discouraged by strong opposition from within the government agencies themselves.

Council's staff advised with the several committees on government reorganization and maintained close contact with those members of both houses of Congress who had to do with reorganization legislation. In spite of the very friendly relationship, however, the public works recommendation of the American Engineering Council and the President's Committee did not become an issue. No specific reason has been given for its omission from the general bills which were introduced, but it is believed to have been considered too provocative.

Assuming that engineers generally agree that most public works are well designed, honestly executed and administered without conscious or deliberate waste or extravagance, Council made the following statement to the Select Committee on Government Reorganization of the United States Senate urging the establishment of a department of public works for the sake of economy in the conduct of government construction business. A public works department was also recommended as an ideal medium for the co-ordination of our engineering and construction resources during periods of economic depression and as a more effective means of mobilization for national defense.

"Engineers believe that the President should have effective managerial authority over the executive branch of the Federal Government commensurate with his responsibility under the Constitution of the United States, but they are not as concerned with strengthening the executive as they are with the larger aim of strengthening the administrative management system of the United States as a whole. They feel that the need for reorganization of the many agencies rests not only on the idea of savings, as considerable as they may be, but upon a very real need for a more economical and effective organization which could be more easily understood and controlled by the people. It is realized the reorganization of the many units of the executive branch of the Federal Government is an enormous undertaking, but engineers urge reorganization under direction of the Chief Executive on the basis of standards set up by Congress to provide up-to-date management for whatever activities may be decided upon by the people.

"Engineers have for many years favored the use of the merit system in personnel administration, and they now endorse the idea of expanding civil service to cover all nonpolicy-determining positions. They recognize the civil service system as a valuable part of government management under a nonpartisan Civil Service Commission and urge salary adjustments throughout the service so that the Government may attract and hold in a career service men and women of the highest character and ability. Such a career is possible only when government service is concentrated and most of its positions are filled through civil service. In that way, opportunities for advancement open up to employees in the whole career system instead of the limited confines of a small service. Under such circumstances, engineers feel that direct appointments by the President should be reduced to a very small number of only the highest positions, and all other civilian positions should be filled by the heads of departments, without fixed term, through civil service with adequate tests to determine fitness.

"Engineers, who have made enormous contributions to the social advancement and economic welfare of their country and to civilization, feel that they are qualified by training and experience to advise their Government regarding engineering and public works activities. On that assumption, they recommend the creation of a public works department to which the President should be authorized to transfer such major engineering and construction work for government agencies as may be practicable. Engineers believe that a public works department should be authorized to co-ordinate the design, construction, operation and maintenance of all large-scale public works which are not incidental to the normal work of other departments, to act as an agent of other departments on engineering public works to administer federal grants to national, state, and local agencies for construction purposes, and to gather information with regard to public works needs and standards throughout the nation. They believe that a relatively small staff could and should direct such work in the hands of engineers in private business throughout the United States, without confusion and waste or the loss of valuable time.

"Such reorganization should promote efficient government in all of its branches, because it is now extremely difficult even for persons charged with executive duties and legislative responsibilities to properly comprehend many of the problems that arise among scores of scattered agencies. As related functions falling in the same field or having the same general purpose could be brought into organic connection and their operations made capable of consideration, as a whole, it should be easier for the Chief Executive to formulate programs for submission to Congress; and the Congress should be able to give more intelligent consideration to legislation and reach less hurried decisions regarding appropriations. The service agencies could perform their work with more certainty, and the public could more readily comprehend the work of the government, more directly exercise that general control which should obtain under a popular government, and more easily transact business with the government's agencies."

Excerpts were included from resolutions by the American Society of Civil Engineers and the American Engineering Council's assembly to the effect that both organizations would support "the enactment of suitable legislation designed to create a federal department of public works, as proposed by the President of the United States, with definite provision for excluding the Army engineers and their river and harbor work from this department." It was also stated that existing working organizations need not be disturbed by the reorganization process, and that all questions involving the redistribution of duties should be subject to decisions by proper authorities in the light of subsequent experience and investigation.

Scientific Research Legislation

Engineers may find much to interest them in the provisions of bill H. R. 7939 instigated by Congressman Randolph of West Virginia, which is "to provide for the promotion of general welfare in relation to the economic efforts flowing from scientific and technological developments" in the United States. It is based on the premise that we must continue to create new "capital outlets," that the chief source of such outlets is the development of new industries, and that scientific research is the foundation of the greater portion of our modern industries.

The bill properly differentiates between social science and natural science and advances a practical philosophy designed to unite the sciences in the application of scientific discoveries and inventions to human needs. One of the principal objectives is the stimulation of pure science as a foundation for applied science which is recognized as the greatest factor in the development of the resources of the nation.

Engineers who have studied the effects of the impacts of technological developments upon civilization may not find much that is new to them in this legislation except that the usefulness of science, pure and applied, to our social and economic well being, as a nation, is appreciated by members of Congress. Even though they may not agree with Congressman Randolph's ideas, engineers have an opportunity to applaud his efforts to effect a national recognition of the true value of technology and to contribute criticisms as well as constructive suggestions to the advancement of that cause.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy, to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Suggestions for AIEE Programs

To the Editor:

At the recent meeting of the Section delegates where Institute publication policies were discussed, the sentiment was almost unanimously expressed that ELECTRICAL ENGINEERING should include a considerable percentage of articles dealing with economic and social aspects of engineering problems, and with readable articles of a general nature. The publication committee will presumably make plans for publishing such general articles, and I infer that the membership at large would similarly like the technical program committee to arrange sessions dealing with general problems.

In thus broadening the Institute field, it is important not to duplicate the programs of other organizations, nor to depart from the factual basis of all good engineering work. It also seems to me desirable to make this departure from our accustomed ways gradually, and especially not to allow controversial subjects of purely political or social nature to displace engineering discussions.

With this in mind, I should like to suggest 3 specific types of articles or discussions for the Institute to add to its programs, or to use more frequently.

First, I think it very desirable to include articles dealing with economics or social problems, so long as these are written from an engineering viewpoint, or on the basis of facts, in such a way that the ideas presented will fit into the framework of engineering knowledge. To me, it appears that the laws of economics are quite analogous to the laws of physics. We have, for example, Hamilton's "principle of least action" which says that in nature motions always occur in such a way as to make the total action of the system a minimum. In economics it appears that society always endeavors to carry out its processes in such a way as to expend the least total effort. We seek to measure effort of every sort, past, present, and future in terms of a common unit, the dollar.

Thus, it should be possible to explain the laws of prices, the development of new industrial processes, and the displacement of old ones, on the basis of a principle of economy of effort as inexorable as the law of gravitation. Looked at in this way, we may think of the laws of economics as engineering principles we are already quite familiar with. And, the task of the engineer may be outlined as that of obtaining a more correct measure of the effort involved in each element of a process, in terms of immediate dollars, and the expression of the laws of variation of effort with changes in the process. As long as only a few individuals or materials are concerned, the problem is simple. However, bringing in the large numbers of individuals, the diverse sources of material, and the long periods of time that must all be considered under modern conditions, makes the problem much more difficult. What the engineer must do is to visualize the laws of economy of effort in simple terms and then widen his vision to include the increasingly large units of society that are involved in modern industry.

I believe there is need for many articles and discussions of economic and social problems prepared along the lines of such an engineering philosophy, and these should form a very desirable addition to the Institute's program. On the other hand, I strongly oppose having the Institute become a forum for the discussion of economic and social subjects in the language and with the methods already used by experts in these fields. We should not attempt to tell the economists or the experts in any other field how to do their job nor criticize them for the way in which they are doing it. We should simply tell men who are trained in engineering how they can apply their engineering knowledge to deal with the economic and social problems they meet in their engineering work.

Second, I think it desirable for the Institute to have articles and discussions of a general expository or descriptive nature, dealing with large-scale engineering projects or application engineering. Engineers need to know what is going on in other fields, to understand its purpose and its importance, and to know where they can find details if they need them. In every field of application engineering, methods and points of view change so rapidly, that nearly every purely technical article is out of date within 5 years. There is, therefore, a large field for periodic articles reviewing the fundamental principles of each branch of engineering and giving references to up-to-date sources of detailed information. Such articles and discussions might well take up as much as one-third of our Institute programs, in my opinion.

Finally, I should like to suggest that the Institute also accept articles and hold discussions on methods by which engineers can play a more important rôle in the world at large. I believe that the Institute can help engineers both by education and by inspiration to gain greater recognition, but such recognition must be the result of their individual actions rather than any prestige conferred upon them by the Institute. Programs should be designed to encourage individual actions by engineers in their own communities, and on no account planned to make the Institute take part as a whole in controversial questions of politics or government. The basis of all engineering progress is fact. Facts must be understood and presented by individuals. They cannot be properly voted upon nor advocated by mass action.

Specifically, I think that in this social field the best way to proceed is for papers to be presented telling just how particular engineers have acted to marshal facts and bring them to the attention of the proper authorities, and have so educated the public as to promote right decisions on affairs of public importance. For example, the method by which the engineers of Cincinnati have organized to interest the public in addresses on engineering subjects should be described before the Institute, thus inspiring engineers elsewhere similarly to bring their facts out in the open. Also, the procedure should be discussed by which any individual engineer may by his interest in the problems of the community in which he lives and the judicial point of view given by his engineering training, bring together community organizations of widely different views and weld them into a force for united public action. Articles in this field which described things of public importance actually done by engineers, or with an engineering—that is, a fact-finding—basis should be of great value and inspiration to the Institute membership.

Summarizing, I believe the Institute ought to enlarge its program to include, first, articles and discussions dealing with economics and social problems described in engineering terms; second, expository or descriptive articles of a general nature showing the state of the engineering art in different fields; and, third, articles describing actual achievements by engineers in the social and governmental field.

Very truly yours,

P. L. ALGER (A'17, F'30)

Engineering General Department, General Electric Company, Schenectady, N. Y.

Branch Activities Are First-Page News

To the Editor:

The first page of the July 1937 issue Electrical Engineering contains a parting message from retiring President MacCutcheon. It is entitled "Branch Activity." When he became president there was no Institute work of which he knew less, and when he retired, there was "no phase in which I am more interested or which I feel is better conducted." He gives 4 columns of observations, anecdotes, and concrete suggestions.

The report of the board of directors in the same issue records the number of branches as 119 with a total of attendance of 46,000.

The number of Enrolled Students is 4,500 and the number of applications of students for membership is 2,250.

Electrical Engineering is publishing articles which give a fine presentation of the engineer in his nontechnical relations. In August, Dean Bush presents his "The Engineer and His Relation to Government." Doctor Flanders, eminent engineering economist, and past-president of the American Society of Mechanical Engineers, deals with "The Engineer in a Changing World." Past-President MacCutcheon visions the engineer of tomorrow. Mr. Blaker, an engineering student, speaks his mind on "The Engineer's Responsibility to Society." Mr. Wilkinson describes an experiment in the recognition of engineers in which the careers and qualities of notable recent graduates are recorded. And, in the September issue, President Doherty of Carnegie Institute of Technology, noted industrial engineer and educator, deals with "Engineering Education and Democracy," and indicates the qualities which the student should develop who aims to be a creative engineer.

All this affords to the engineering student a wealth of information, suggestion, and guidance.

This material might well afford the subject matter for presentation and discussion at student Branch meetings. It presents various phases of the larger engineering career which the future opens to the engineering student of today.

Very truly yours,

C. F. Scott (A'92, F'25, HM'29,
past-president, member for life)

Professor of Electrical Engineering Emeritus,
Yale University, New Haven, Conn.

Graphical Solution of Similar Impedances in Multiple

To the Editor:

Figure 2 illustrates a simple method of determining the equivalent impedance of 2 similar impedances in multiple, such as the pair illustrated in figure 1. It must be remembered that the ratio of reactance to resistance in each branch is the same. The construction is as follows: Choose any desired reference or base line as AB. Erect perpendiculars to this base line at any desired distance apart and of lengths, to any convenient common scale, equal to the impedances, as $Z_1 = 8$ and $Z_2 = 5$. With diagonals join the opposite ends of the perpendiculars as shown by the dotted lines. Then, the equivalent impedance of the multiple combination is, to the common scale, the length of the perpendicular from the intersection of the diagonals to the base line, as shown by Z_{12}.

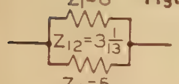


Figure 1 (left)

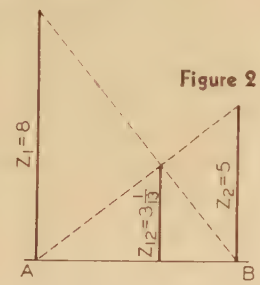


Figure 2

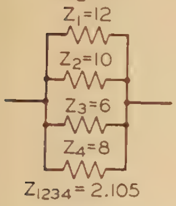


Figure 3

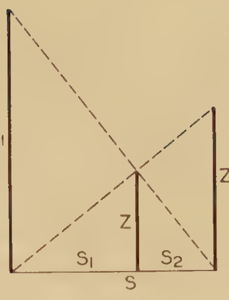


Figure 6

For more than 2 similar impedances in multiple, as in figure 3, they may be grouped in pairs and the resultant of the pairs combined as in figure 4; or take the resultant of the first 2, work it with the third, then the resultant of this combination is worked with the fourth; etc. This is illustrated in figure 5. A comparison of figures 4 and 5 will show that the resultant Z_{1234} is the same in either case.

The equivalent resistance of a group of multiple resistances or the equivalent reactance of a group of multiple reactances may be determined graphically in this way, they being special cases of similar impedances in multiple.

Proof: From similar triangles in figure 6:

$S_1/Z = S/Z_2$, therefore $S_1 = ZS/Z_2$ and $S_2Z = S/Z_1$, therefore $S_2 = ZS/Z_1$

Therefore $S_1 + S_2 = ZS(1/Z_1 + 1/Z_2)$; but $S_1 + S_2 = S$;

therefore $S = ZS(1/Z_1 + 1/Z_2)$, or

$1 = Z(1/Z_1 + 1/Z_2)$ or $1/Z = 1/Z_1 + 1/Z_2$ or

$$Z = \frac{Z_1Z_2}{Z_1 + Z_2}$$

It will be noted that the expression is the well-known one for similar impedances in multiple. Also it is evident that the expressions are independent of the distance, S, between perpendiculars.

Very truly yours,

E. C. Goodale (A'27)

Inspector, Puget Sound Power and
Light Company, Olympia, Wash.

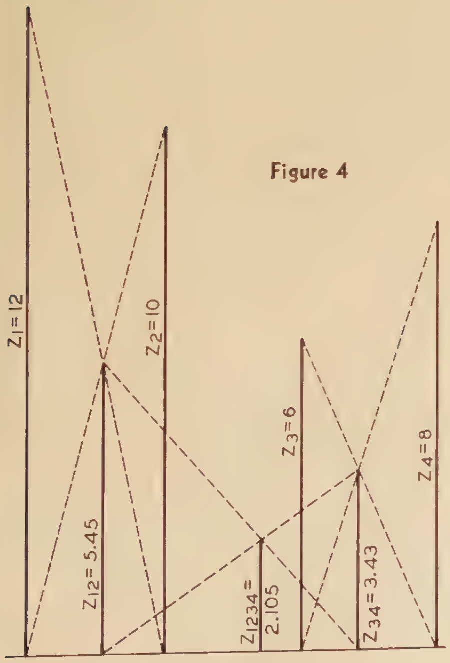


Figure 4

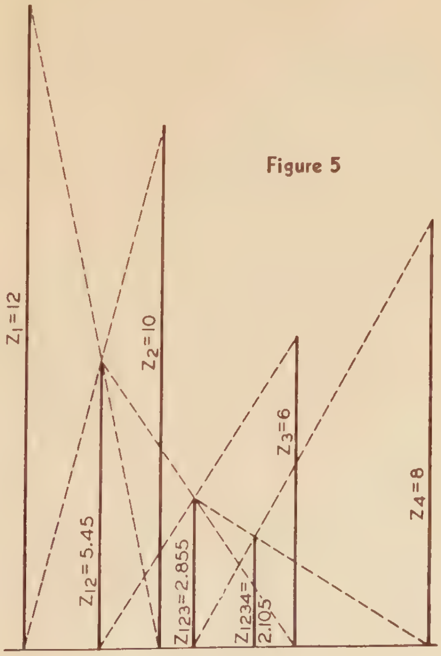


Figure 5

On the Characteristics of Human Nature

To the Editor:

Should it be required to state a term which, more uniquely than any other, supposedly characterizes western civilization the adjective "scientific" will not long fail to appear. It is commonly held that this term is peculiarly applicable in that other, or preceding, social systems lack the same. Some inspection of the matter at a critical level discovers, however, a slight confusion.

Presumably the uninitiated might gather that society is employing scientific method in day-by-day effort toward improvement. Search among popular or discriminating opinion discloses little such deliberated action as admitted, as contemplated, or as reasonably possible.

The exceptional suitability of scientific method and engineering persons to cope with the present untidy state of human affairs is widely admitted. After considering the method of action of engineers, it becomes plain there is no class of mortals less likely to be permitted undisguised use of its characteristic technique.

This is all as it should be in a world where men speak of "better things" with wistful optimism and concurrently are capable mainly of invidious self-regard and of acting largely through evidenced demonstrations of force and chicane.

But, regardless of such being the reality of the matter, there still remains an urge on technically biased persons to act for an improved social order. Admit the engineers to be as willing as the need is great; as yet there is little detailed information in the literature to aid the rank and file in its action on a creaking human polity.

No small part of the engineer's approach and method has been his insistence on the dimensions and behaviors of the material he must handle. If, therefore, he must now act on men in a society rather than supervise them in industrial pursuits, he might reasonably seek a chart of performance of this substance with which he is to deal. A quantity so varied and immense as the human animal can never be precisely covered. Any attempt must necessarily be fragmentary, even tedious. Nevertheless, the importance of having some basis for action, superficial and "practical" though it be in contrast to rigorous and theoretical, warrants almost any attempt at record.

With these limitations in mind, and with some misgivings as to the form of the data, the following notes are presented.

Some Characteristics of Human Nature

We hug deformities if they bear our name—Glanville

A. Human nature possesses but little constructive imagination.

Reasons

Its philosophy is one of belief in pragmatic effectiveness, in results, in the value of experience, in cynical practicality. E.g., its expression "Nothing succeeds like success."

Consequences

1. Learns slowly, if at all, and largely through action on its pocketbook. Therefore repetitions and detaily; easily flustered by any unexpected response of man or machine.

2. Unable to "see" much of anything through eyes or experiences of others.

3. Able to concede experiences, knowledges or skills to others only if gained in its "presence."

4. Unable to see any personal repercussions of its instinctive social and economic indifferentism.

5. Lacks that capacity for intellectual indignation which was called to the attention of the ancient Greeks, and which is essential to the preservation of a democracy. (This in contrast to an urgent interest in sensationalism.)

6. Capable of academic consideration of but few topics. Therefore (*a*) must be able to "take sides" on matters to become interested—must become personally identified. And this possible interest is

   I. In direct ratio to personal or financial concern with the matter.
   II. Without much regard to the social or economic principles involved in an "isolated" event.
   III. Exploitable through sales efforts appealing to the more paltry emotions.

7. Distrustful, both of itself and of others. But it is extremely vocal in its own defense.

8. Amenable to power rather than to intellectual discipline. Therefore (*a*) responsive to the compulsions of organization rather than to the demands for responsibility in co-operative independence; (*b*) impressed by bigness—physical or financial.

9. Subjective rather than objective. Therefore (*a*) pays little attention to what others say. (*b*) gives much consideration to the words put into other's mouths. (*c*) intrigued by labels, e.g., "smartness," "exclusive import," "Republican," "New Deal."

10. Seeks distinction, while demanding to be just like everyone else.

11. Cherishes a naive belief that mass emotional satisfaction is possible in a social order based on competitive gain.

B. Human nature is a gregarious one.

Reasons

1. Lacks self-reliance.

2. Necessary that it act on people—competitively—if it is to sense "accomplishment."

Consequences

1. Worst form of insult to it or by it is a considered removal of physical presence.

2. Naturally urban (as regards population density).

3. Prone to bother people by invasions of space, time, or thoughts.

4. The "pleasing effrontery" of sales techniques is acceptable to it.

C. Human nature is emotional rather than rational.

Reasons

1. It has "gotten by" in the mass, fairly acceptably up to now.

2. Mental inertia, coupled to unfamiliarity with and distrust of reasoning processes.

Consequences

1. It avoids thinking processes by every means at its disposal. Therefore, it is prone to rely on its instincts when under stress.

2. It is arrogant.

(*a*). Particularly in the sense that it must pursue personal vindication through any amount of conversational bramble patches.

(*b*). Seemingly it cannot consider itself as other than unique, thus can accept nothing less than—

   I. Instant, unquestioning obedience.
   II. Complete, enthusiastic agreement with its prejudices, under the name, that is, of "judgments."

3. It is unctuous. Therefore:
(*a*). Prone to rely on symbolic action.
(*b*). Smug.
(*c*). Apt to make virtues of necessities, that is, to rationalize its compelled behaviors.

4. It is basically disagreeable.

Reasons. 1. Mass emotional satisfaction based on competitive gain is a self-contradictory concept.

Results. (*a*) Impatient, irritable, spiteful, malicious; (*b*) instinctively uses the *argumentum ad hominem;* (*c*) attempts extreme emphasis by becoming personally abusive; (*d*) stubborn, contrary, selfish, acrimonious, rancorous; (*e*) excitable and "nervous" particularly in presence of recognized personalized challenges to its "rights."

5. Hypersensitive to any possibility of critical implication in words or actions of others. Therefore, (*a*) possessed of a bustling, impressive activity; (*b*) rushes spontaneously to its own verbal defense; that is, it is "touchy" so is prone to argue by begging the question; (*c*) easily becomes indignant over its assignments of professed rectitude to others; (*d*) bristles easily.

6. Unable to carry on true argumentation.

7. Though "sporty" lacks many elements of true sportsmanship; hence (*a*) is unsuited to interdependent social and economic existence.

8. Its standards are largely pecuniary as distinguished from economic, intellectual, scientific, etc.

9. Its philosophical bias can be put as: *Ejus cogito igitur id est*, as opposed to Descartes' statement *Cogito ergo sum*.

References

Note. The list of works given below serves somewhat the purpose of a bibliography. No claim whatsoever can be made as to completeness in the assembly. The literature on this subject grows each day. What appears here will but offer the interested reader a slightly enlarged field of inquiry.

Should he wish practical reference for day-by-day use in small compass, let him possess himself of an old-fashioned rhetoric book. There he will come upon those methods making most appeal to the common run of mankind in argumentation—vicious circle and *post hoc* reasoning, begging the question, the *argumentum ad hominem*, etc. Superficial and fallacious though they be, their general applicability will be apparent. Then, let him add a copy of Rostand's "Cyrano de Bergerac" to recognize the relish for *quel geste* and its fruits.

The other works, as available, will assume their places in the perspective.

Books

The Mind and Society, Pareto.
Dynamic Sociology, Lester Ward.
On the Biological Basis of Human Nature, Herbert Spencer Jennings.
An Introduction to the Philosophy of Education, Demiaskevich.
History of the Great American Fortunes, Meyers.
Halsey's Handbook (particlarly the section on the metric system in editions of about 1915)
Debt and Production
Horses and Apples
Bassett Jones.
The Theory of the Leisure Class
The Place of Science in Modern Civilization
The Engineers and the Price System
Veblen.
The Epic of America, Adams.
The Rise of the New West
Significance of the Frontier in American History
Frederick Jackson Turner.
The Condition of the Working Class in Britain, Hiett. (See also Engles' treatise of the same title dated 1844.)
Psychopathia Sexualis, Krafft-Ebbing.
Liberty, Everitt Dean Martin.
Moral Man and Immoral Society, Niebuhr.
Where Is Science Going? Max Planck.
The Modern Corporation and Private Property, Berle and Means.
Christian Fact and Modern Doubt, Buttrick.
Monographs of the President's (Hoover) Research Committee on Social Trends in the U. S.
Middletown
Middletown in Transition
R. S. and H. M. Lynd
The Symbols of Government, Thurman Arnold.
Government of the People, Brogan.
The Tragic Era, Bowers.
Graft in Business, Flynn.
The Insolence of Office, W. B. and J. B. Northrup.
The Politician, Wallis.
Wm. Randolph Hearst, an American Phenomenon, Winkler.
Dynamite, Louis Adamic.
Democratic Despotism, Desvernine.
Fifty-Five Men, Rodell.
Deserts on the March, Sears.

Tools of Tomorrow, Leonard.

Sticks and Stones, Louis Mumford.

The Engineer Sells His Services, Hirst.

How to Win Friends and Influence People, Dale Carnegie.

(There are some very pertinent remarks on these types of "success" books in the "Readers Guide" of *New York Herald Tribune* "book review section" of April 18, 1937.)

Fictionalized Material

Tono Bungay, Wells.

Oil for the Lamps of China, Hobart.

Life With Father, Day (and enthusiastic reviews of the same.)

I Can Get It for You Wholesale, Weidman.

The Forty Days of Musa Dagh, Werfel.

The Cherry Orchard; The Three Sisters, plays by Anton Tcheckhov.

Periodical Literature

Is Man an Absurdity, Bradley. *Harpers*, October 1936.

Trusting in Brains, Canby. *Saturday Review of Literature*, June 13, 1936.

Science and the Layman, Sullivan. *Atlantic Monthly*, September 1934.

Design for a Book, Lippmann. *Atlantic Monthly*, September 1936 (and subsequent essays by the same author in this magazine).

The Success Fetish in Education, Steiner. *Phi Delta Kappan*, December 1936.

The Status Quo, Tindsley. *Modern Language Journal*, February 1937.

Report of the American Historical Society on Social Studies in Education (and, some pertinent remarks on the subject by L. E. Akeley, *Journal of Engineering Education*, May 1935).

Speech of Harold Urey at dedication of Mellon Institute, May 6, 1937. ("this is age of dissipation of natural materials of earth's crust," etc.)

Eighth Steinmetz Lecture, Mees. Electrical Engineering, March 1934.

Very truly yours,

Andrew Douglas (A'18, M'29)

Physics and General Science
Teacher, Murphy High School,
Mobile, Ala.

AIEE Publications

To the Editor:

I have read with much interest Michel G. Malti's letter in the September issue of Electrical Engineering, as it expresses not only a thought I have had for some years, but also a thought I have heard expressed by many other engineers. I would go further than Mr. Malti and estimate that the number of engineers in class *b* would far exceed those in both classes *a* and *c*.

I confess quite freely that the biggest proportion of the articles appearing in Electrical Engineering are so technical in nature that I am unable to follow them and, in fact, would have no interest in following them except in a few cases where, for some reason or other, I have a personal interest in the subject under discussion. I realize that due to the amount of specialization in the engineering field it would not be possible to have many highly technical papers applicable to the various fields of specialization, but I nevertheless feel that in a magazine which is for the whole membership the articles should, if possible, be of interest to a majority of members.

It is realized that as editor of a magazine for so diverse a group of people you have a most difficult job but, nevertheless, it may be of interest and perhaps of some help to you to learn what a number of your readers think, and I know from personal contacts that I am speaking for a number rather than for myself alone when I endorse Mr. Malti's program.

Very truly yours,

M. M. Brandon (A'34, M'36)

Associate Electrical Engineer, Underwriters'
Laboratories, Inc., New York, N. Y.

Heat Transfer Efficiency of Range Units

To the Editor:

The interesting article by W. James Walsh published in the August issue of Electrical Engineering has just come to my attention. It is certainly an excellent article.

In the interest of bringing out the true values of the diverse designs of electrical range units, I would like to make the following comments and suggestions which may possibly help to guide future and more thorough studies of this subject with the idea of setting up modes of test and examination to bring out comparatively all the qualifications of every type of unit.

My first comment, of course, is that the tests on which this paper was based are tests only on the stated units in their brand new condition and are, of course, laboratory tests rather than cooking tests extending over a period of time such as will demonstrate what I term the quality of "stability of efficiency" and "cooking and heating efficacy over an extended time period."

We all know, of course, that the true value of a heating unit or an electrical range is not fully demonstrated by what might be termed an instantaneous test when the equipment is brand new. Such equipment does not stay brand new.

It is subject to all kinds of use and abuse in practical household work and the buyer is naturally interested in the performance of the devices throughout the period of normal life expectancies.

Would it not be an excellent thing to have these tests repeated after each of the units has been in normal practical and identical cooking use approximating as nearly as possible household use in a family of average size?

Of course, there is always some little difference in ohmic resistance of units when new and the cooking tests on the new units ought to be made at identical rated wattage regardless of the voltage required on the new units.

Better still would be to have selected new units of each make which would have identical ohmic resistance or, in other words, which would possess identical normal rated wattage when new and then let the units be operated as above stated and tested subsequently at periods of 3, 6, 9, and 12 months practical use at the voltage which originally gave the normal rated wattage when new. This test should include boiling speed tests and other practical cooking tests at the identical original voltage.

Then after having made such tests, the efficiency tests should be repeated at the same voltage.

Then a third set of tests should be made under which condition the voltage applied to each unit might be increased so as to reestablish the original rated wattages on each unit and the efficiency test repeated.

In this way it would take account of the "stability of efficiency" and of "operating efficacy" after various periods of elapsed time during which the units had all been in identical and practical cooking use.

This would really show up what the market wants to know, which is not merely what a brand new article will do on a laboratory test in the way of a technical expression of electrothermal efficiency, but it would demonstrate the stability of the various qualities of the various units and would also demonstrate efficacy of which the efficiency is only one component.

I realize that the making of such tests under conditions that would be fairly identical as between units and also fairly comparative to practical use would involve some painstaking care and experience, but it would certainly be more nearly the proof of the pudding short of actual market experience on the part of the public.

I hope that these suggestions may be of some value in assisting efforts along this line.

Very truly yours,

E. L. Wiegand

President, Edwin L. Wiegand Company,
Pittsburgh, Pa.

To the Editor:

Mr. Walsh's paper in the August issue of Electrical Engineering should go a long way in awakening the range designers to the fact that the modern electric range is an outgrowth of the old-time wood and coal range rather than the result of good engineering design. His efficiencies of heat transfer are suprisingly high, probably higher than one would find in the average kitchen. He used square-cornered utensils, whereas most range users use all types of round-cornered and odd-diametered utensils. His efficiencies would have been considerably lower had he used a random assortment of utensils such as one finds in the average kitchen.

In the not-far-distant future a complete range will include the utensils which are to be used with it. These utensils will be of such diameter as to cover the unit completely, and will have black bottoms and square corners (similar to those shown by Mr. Walsh), although square-cornered utensils are difficult to clean. A minimum of surface units will be built into the range however; most of them will be the well-type of unit, such as is now included in modern ranges as an "economy" unit. It is also likely that surface utensils and their covers will be insulated against heat radiation from their sides and tops. There is the possibility that some day immersion units will be adapted to boiling and stewing operations, thus raising the efficiency of heat transfer to the highest possible value.

Mr. Walsh is to be highly commended for bringing to the attention of electrical engineers quantitative data on a problem which has too long been subject to much speculation without factual basis.

Very truly yours,

Walter J. Seeley (A'19, M'28)

Professor and Head of Department of Electrical
Engineering, Duke University, Durham, N. C.

Personal Items

C. R. Jones (A'16, M'30, director) eastern transportation manager, Westinghouse Electric & Manufacturing Company, New York, N. Y., has been elected chairman of the Institute's committee on finance for the year 1937–38. He was born at Norristown, Pa., May 11, 1886. In 1907, he was graduated from the University of Pennsylvania with the degree of bachelor of science in electrical engineering. Since 1907 he has been continuously with the Westinghouse Electric & Manufacturing Company. For the first 2 years, until 1909, he was on the engineering apprentice course of the company at East Pittsburgh, specializing in railway work. For the next 2 years, until 1911, he was in the engineering and railway department of the company, also at East Pittsburgh, being transferred in the latter year to the New York office where he was assistant to the manager of the railway division until 1916. From 1916 to 1925 he was sales engineer in the New York office of the Westinghouse company, representing the company on large contracts involving both engineering and commercial phases. This included work in connection with the electrification of steam railroads and power supply and car equipment for the local rapid transit company. From 1925 to 1930, he was section manager of the transportation division of the New York office, continuing the same work, but in a supervisory capacity. In the latter year he became assistant northeastern transportation manager, and in 1931 transportation manager of what is now the eastern district. Mr. Jones is at present a director of the Institute and has served as a member of the national membership committee, 1928–31, and has engaged for a number of years in the activities of the New York City District (number 3). He has been active for several years in connection with the Institute's winter conventions. He is a member of the New York Electrical Society, New York Engineers' Club, and other organizations.

L. W. W. Morrow (A'13, F'25, past director) general manager of the fiber products division of the Corning (N. Y.) Glass Works, has been appointed chairman of the Institute's committee on constitution and bylaws for the year 1937–38. Mr. Morrow is a native (1888) of Hammond, W. Va., and was graduated from Marshall College in 1907 and Cornell University in 1911. During the scholastic year following his graduation in 1911 he served as an instructor at Cornell University, and in 1913 was appointed assistant professor of electrical engineering at the University of Oklahoma. During the year 1917–18 he served as professor of electrical engineering and director of the school of electrical engineering, before becoming assistant director of the U.S. Signal Corps school at Yale University. He served concurrently as an assistant professor of electrical engineering on the faculty of Yale University, and, following the World War, was retained in that position. In 1922 Mr. Morrow accepted a position as associate editor of *Electrical World;* in 1929 he became editor of that publication, but resigned in 1936 to become manager of the fiber products division of the Corning Glass Works. He has been active in the committee work and other affairs of the Institute, is at present a member of the technical program committee and the committees on co-ordination of Institute activities and publication. He is vice-president of the Thomas Alva Edison Foundation and the Institute's representative on the Engineers' Council for Professional Development. Mr. Morrow is a member of The American Society of Mechanical Engineers, American Electrochemical Society, and Sigma Xi.

J. W. Barker (M'26, F'30) dean of engineering, Columbia University, New York, N. Y., has been appointed chairman of the Institute's committee on education for the year 1937–38. Dean Barker was born June 17, 1891, at Lawrence, Mass., and was graduated from Massachusetts Institute of Technology with the degree of bachelor of science in electrical engineering in 1916, and master of science in electrical engineering in 1925. During the World War he served in the Coast Artillery Corps of the United States Army as artillery engineer and adjutant, and also as officer in charge of civil affairs of the American forces in Germany following the war. In 1925 he was appointed associate professor of electrical engineering at Lehigh University; 1929 he became professor and head of the department of electrical engineering, but in the following year was appointed professor and dean of the faculty of engineering at Columbia University, where he has remained since. Dean Barker has been a member of the Institute's committee on education since 1930, has served on the committee on production and application of light since 1929, and was chairman of that committee from 1933 to 1935. He was a member of the technical program committee from 1932 until 1937, and is at present a member of the publication committee and an Institute representative on the Iwadare Foundation. He is a member of the American Association for the Advancement of Science, American Society of Civil Engineers, The American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, Society for the Promotion of Engineering Education, and has been active in the affairs of the division of engineering and research of the National Research Council.

W. D. A. Peaslee (A'10, F'27) consulting engineer, Indianapolis, Ind., has joined the staff of W. S. Dickey Clay Manufacturing Company, Kansas City, Mo., as chief engineer. Mr. Peaslee was born at Grass Valley, Calif. He received the degree of bachelor of arts in electrical engineering from Leland Stanford, Jr., University in 1910, and that of electrical engineer in 1916 from Oregon Agricultural College, where he was an instructor. Following service as a captain in the U.S. Army during 1917–19, he became electrical engineer and later general manager of the Jeffery Dewitt Insulator Company, Huntington, W. Va. From 1922 to 1924 he was chief engineer of Belden Manufacturing Company, Chicago, and during 1924–25 was president and general manager of Terlee Electric and Manufacturing Company, Chicago. In 1925 he became assistant to president and general manager of Daven Radio Corporation, Newark, N. J., and 2 years later accepted the position of assistant to president, Underwriters Laboratories, Chicago, Ill., which he held for 8 years. He is the author of articles on a variety of subjects, and a member of The American Society of Mechanical Engineers, American Association for the Advancement of Science, Société Française des Electriciens, and others.

O. J. Rotty (A'25, M'31) superintendent of substations, Union Electric Company of Missouri, St. Louis, has been appointed chairman of the Institute's committee on automatic stations for the year 1937–38. Mr. Rotty was born October 14, 1898, at St. Louis and received the degree of bachelor of science in engineering at the University of Missouri in 1921. Immediately following his graduation he entered the employ of the Union Electric Light and Power Company, which later became the Union Electric Company of Missouri. His first position with that company was concerned with the physical inventory of the utility properties, but in 1923 he was appointed general substation engineer, in which capacity he worked on the

L. W. W. MORROW

J. W. BARKER

C. R. JONES

construction, testing, and operation of automatic substations. From 1926 until 1930 Mr. Rotty was substation engineer in charge of design, construction, testing, and inspection of automatic stations, and since 1930 he has been superintendent of substations. He has been a member of the committee on automatic stations since 1930, and has been an interested participant in the affairs of the Institute's St. Louis Section, having been Section secretary during 1929–30 and member or chairman of Section committees.

R. D. Evans (A'21, M'26) central station engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., has been appointed chairman of the Institute's committee on power transmission and distribution for the year 1937–38. Mr. Evans was born October 14, 1892, at Spring Water, Wis., and received the degree of bachelor of science in electrical engineering at the University of Oklahoma in 1914, following which he entered the employ of the Westinghouse Electric & Manufacturing Company as a general engineer. He has been affiliated with that company continuously, and has done much original work in studies of power generation and transmission, a-c railway engineering, electric furnaces, and inductive co-ordination. Mr. Evans has served the Institute as a member of the power transmission and distribution committee since 1924, and was a member of the committee on communication from 1924 until 1934; he was active also in the committee work of the former National Electric Light Association. He has presented several papers, principally on transmission-line calculations, power system stability, and network theory, before the Institute, and is co-author of a textbook on the theory of symmetrical components. In 1929 he was awarded the Triennial Montefiore Prize jointly with C. F. Wagner (A'20, M'27) for contributions to the theory of power system stability.

F. V. MAGALHAES

VANNEVAR BUSH

O. A. KNOPP

W. L. Everitt (A'25, F'36) professor of electrical engineering at The Ohio State University, Columbus, has been appointed chairman of the Institute's committee on communication for the year 1937–38. Doctor Everitt was born April 14, 1900, at Baltimore, Md., and received the degrees of electrical engineer (1922), master of science (1926), and doctor of philosophy (1933), at Cornell University, the University of Michigan, and The Ohio State University, respectively. Following his graduation in 1922 he became affiliated with the North Electric Manufacturing Company, Galion, Ohio, as engineer in charge of the design and installation of relay-operated private automatic telephone exchanges. In 1924 he was appointed to the electrical-engineering faculty of the University of Michigan, was placed in charge of the courses in communication, and remained at that institution until 1926 when he was appointed assistant professor of electrical engineering at The Ohio State University; in 1929 he became associate professor; and in 1934, professor. Besides his regular teaching duties, Doctor Everitt has served as consulting engineer for several companies. He has been active in the local affairs of the Columbus Section of the Institute, having been Section chairman during 1931–32, and has served as a member of the committee on communication since 1932. He is author of a widely used textbook on communication engineering.

O. A. Knopp (A'09, M'34) chief of the bureau of tests and inspection, Pacific Gas and Electric Company, San Francisco, Calif., has received the AIEE Pacific District prize for initial paper for his paper "Some Applications of Instrument Transformers." Mr. Knopp was born August 24, 1877, in Berlin, Germany, and received his technical education in that country. His first position in the electrical industry was as a testing engineer in the Bergmann Electrical Works, Berlin, in 1900. After several brief affiliations with companies in both Germany and the United States, he became superintendent of the standardizing laboratory and meter department of the Pacific Gas and Electric Company in 1908. In 1915 Mr. Knopp was made superintendent of the laboratory department; and in 1920, chief of the bureau of tests and inspection. He is a member of the American Society for Testing Materials, and was a long-standing member of the former National Electric Light Association. He served as a member of the Institute's committee on instruments and measurements from 1930 to 1934, and holds many patents on improvements in instruments and transformers.

R. R. Whipple (A'30, M'36) assistant professor of electrical engineering at the University of Iowa, Iowa City, has accepted the position of designing illuminating engineer with The Trippe Manufacturing Company, Chicago, Ill. Mr. Whipple is a graduate of the University of Michigan, and had been a member of the faculty of the electrical engineering department at the University of Iowa since 1928. He has written several papers on illumination subjects, and is a member of the Illuminating Engineering Society.

F. V. Magalhaes (A'07, F'19) executive assistant to the president, Consolidated Edison Company of New York, Inc., New York, N. Y., has been appointed chairman of the Institute's board of examiners for the year 1937–38. A biographical outline of Mr. Magalhaes's technical career and his activities in the Institute appeared in Electrical Engineering for August 1937, page 1064.

Vannevar Bush (A'15, F'24, director, Lamme Medalist '35) vice-president of Massachusetts Institute of Technology, Cambridge, has been appointed chairman of the Institute's committee on co-ordination of Institute activities for the year 1937–38. A biographical sketch of Doctor Bush appeared in the March 1937 issue of Electrical Engineering, pages 394–5.

J. W. McRae (A'37) member of technical staff, Bell Telephone Laboratories, Deal, N. J., has received the AIEE Pacific District prize for Branch paper for his paper "The Magnetic Vector Potential," which was published in Electrical Engineering for May 1936, pages 534–42, and presented

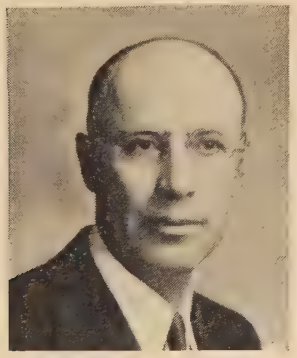
O. J. ROTTY

W. L. EVERITT

R. D. EVANS

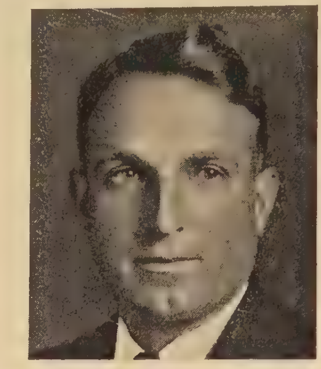
at the 1936 AIEE summer convention, Pasadena, Calif., June 23, 1936. Doctor McRae was born October 25, 1910, at Vancouver, B. C., Canada, and received the degree of bachelor of applied science at the University of British Columbia in 1933, following which he entered California Institute of Technology as a graduate student and received the degrees of master of science (1934) and doctor of philosophy (1936). He has been a member of the technical staff of the Bell Telephone Laboratories since January 1937. He is a member of Sigma Xi.

J. A. Koontz, (A'11, M'20) hydroelectric and transmission engineer, Pacific Gas and Electric Company, San Francisco, Calif., co-author of the paper "Cable Vibration—Methods of Measurement" with J. S. Carroll (A'24, M'37) has received the AIEE Pacific District prize for best paper. Mr. Koontz was born August 27, 1883, at Aztec, N. M., attended Throop Polytechnic Academy, received the degree of bachelor of arts at Stanford University in 1908 and the degree of electrical engineer at the same institution in 1912. Upon graduation in 1909 he was employed by the General Electric Company for one year before he returned to Stanford as a graduate student and instructor, and after he received his engineering degree in 1912 he became associated with the Great Western Power Company, San Francisco, where he eventually became electrical engineer and remained until 1930. In that year he assumed his present position with the Pacific Gas and Electric Company. He has served as a member of 2 of the Institute's committees: power transmission and distribution, 1920–23; and membership, 1931–33.



J. A. KOONTZ

H. J. McCreary (A'24, M'36) has resigned as chief engineer of the Leich Electric Company, Genoa, Ill., to establish an office as a consulting engineer at Chicago. A graduate of the University of Nebraska, from which he received the degree of bachelor of science in electrical engineering in 1923, Mr. McCreary was employed by the Western Electric Company, Chicago, as inspection methods and development engineer from 1923 to 1925, and by the Automatic Electric Company, Chicago, as research engineer from 1925 to 1928. For one year he was laboratory engineer with the Grigsby-Grunow Company, Chicago, and for 3 years was development engineer for the Railroad Supply Company. From 1933 to 1935 he was chief engineer of the Chicago Television and Research Laboratories, and in 1936 became chief engineer of the Leich Electric Company. He has patented several inventions,-and is a member of the Western Society of Engineers.



J. S. CARROLL

J. S. Carroll (A'24, M'37) associate professor of electrical engineering, Stanford University, Calif., co-author of the paper "Cable Vibration—Methods of Measurement" with J. A. Koontz (A'11, M'20) has received the AIEE Pacific District prize for best paper. A biographical sketch of Doctor Carroll appeared in the August 1937 issue of Electrical Engineering, page 1064, in announcement of his receipt of honorable mention in the AIEE national prize awards for best paper in theory and research.

J. T. Robertson (A'06, M'13) recently at Muscle Shoals, Ala., is now connected with the firm of J. T. Robertson and Associates at Birmingham. A graduate of Clemson College in the class of 1903, he was electrical inspector for the Southeastern Underwriters' Association, Atlanta, Ga., until 1911, when he became electrical engineer and inspector for the Mississippi Inspection and Advisory Rating Company at Vicksburg. Later he was made secretary as well as electrical engineer, a position which he held until 1925 when he became superintendent of the Abbeville (S. C.) Water and Electric Plant. In 1929 he became connected with A. H. Turner, Atlanta, as special agent and engineer.

E. L. Ginzton (Enrolled Student) has received the AIEE Pacific District prize for graduate student paper for his paper "Balanced Feed-Back Amplifiers." Mr. Ginzton is a native (1915) of Russia and an electrical-engineering graduate of the University of California in the class of 1936. Following his graduation he returned to that school to pursue graduate studies.

A. L. Turner (M'29) chief engineer, Northwestern Bell Telephone Company, Omaha, Neb., has been appointed a member of the engineers and architects board authorized recently in a bill passed by the state legislature, which empowers the board to administer an act calling for licensing of engineers and architects in the state.

W. H. Hulswit, Jr. (A'34) who has been a fellow at Northwestern University at Evanston, Ill., now is employed in the development department of United States Rubber Products, Inc., at Passaic, N. J.

G. P. Knapp (A'30) former field engineer with RCA Manufacturing Company, Inc., at Camden, N. J., is now service manager for the company at Baltimore, Md.

F. E. Leggett (A'32) recently chief draftsman for an improvement project at the University of Florida, Gainesville, is now at Tallahassee as draftsman in a highway planning survey division of the Florida State Road Department.

K. J. Krach (A'37) who has been serving with the 34th Infantry, U.S. Army, at Fort George G. Mead, is now employed by the Pennsylvania Water and Power Company at Baltimore, Md., as electrical engineer.

L. M. Sorenson (A'34) who has been a draftsman for the Beloit Iron Works, Beloit, Wis., is now assistant electrical engineer in the inspection and development laboratory of the Western Electric Company at Chicago, Ill.

C. H. Johnson (M'35) who has been electrical engineer for the Idaho Maryland Mines Corporation, Grass Valley, Calif., has accepted the position of electrical engineer with the General Electric Company, San Francisco.

W. M. Gilman (A'27) engineer for the Waterbury Tool Company, Waterbury, Conn., now is employed as an engineer for the consulting engineering firm of Jackson and Moreland, Boston, Mass.

W. F. Uffelman (A'34) has been transferred from the sales engineering department of the Clark Controller Company, Cleveland, Ohio, to the Detroit, Mich., offices of that company, as a district sales engineer.

J. H. Persons (A'31) employed in the industrial department of the General Electric Company, Atlanta, Ga., has been transferred to the Charleston, S. C., offices of that company.

L. F. Pries (A'33) formerly development engineer for The Rudolph Wurlitzer Company, DeKalb, Ill., now is employed in the engineering department of the American Steel & Wire Company, DeKalb.

M. D. Brane (A'28) formerly a teacher of applied electricity in the Haaren High School, New York, N. Y., now is employed by the Duquesne Light Company, Pittsburgh, Pa.

C. E. Gagnier (A'34) formerly electrical foreman, Rotary Electric Steel Company, Detroit, Mich., now is development engineer for The DeVilbiss Company, Toledo, Ohio.

F. S. Rothe (A'36) formerly a cadet engineer for the Metropolitan Edison Company, Reading, Pa., now is employed in the test department of the General Electric Company, Pittsfield, Mass.

W. S. Gifford (A'16) president, American Telephone and Telegraph Company, New York, N. Y., has been appointed chairman of the advisory committee on communication of New York World's Fair, 1939.

S. V. Wadthekar (A'34) formerly chief engineer of the Arrah (India) Electric Supply Co., Ltd., now is resident engineer and deputy manager of the Rewa (India) Electric Supply Co., Ltd.

E. G. Hemenway (A'20) district manager, Western Electric Company, Inc., of Cuba, Balboa, Canal Zone, has been transferred to the New York, N. Y., offices of Electrical Research Products, Inc.

A. R. Nahrgang (A'24) has been transferred from the staff of Electrical Research Products, Inc., New York, N. Y., to the Kearny, N. J., plant of the Western Electric Company.

N. S. Moore (A'17, M'19) recently was appointed a member of the sales organization of The Porcelain Insulator Corporation, Lima, N. Y., with offices at Riverside, Ill.

R. J. Abramson (A'33) formerly electrical engineering draftsman with Joseph Weidenhoff, Chicago, Ill., now is industrial engineer with Max Miller Company, Chicago.

C. B. Smith (A'35) test man with the General Electric Company as Schenectady, N. Y., has been transferred to Fort Wayne, Ind., as fractional-horsepower-motor engineer.

L. L. Lathrop (A'35) formerly with the Industrial Heater Company, New York, N. Y., now is employed by the New York Power and Light Company at Schenectady, N. Y.

L. A. Grettum (A'24) operating manager of the Eastern Oregon Light and Power Company, Baker, recently was elected vice-president of the Northwest Electric Light and Power Association.

Nikola Tesla (A'88, F'17, Edison Medalist '16, member for life) recently received the Order of the White Lion of the Republic of Czechoslovakia for his contributions to science and engineering.

T. O. Sweatt (A'33) has resigned from the staff of Gibbs and Hill, consulting engineers, New York, N. Y., and now is employed by the Public Service Electric and Gas Company, Newark, N. J.

R. S. Taylor (A'36) division engineer, Oklahoma Gas and Electric Company, Oklahoma City, has been transferred to the Muskogee offices of that company.

D. H. Andrews (A'35) who has been an experimenter in the Naval Research Laboratory, Anacostia, D. C., now is an assistant electrical engineer with the General Cable Corporation, Buffalo, N. Y.

J. W. Lindsey (A'33) formerly electrician with the U.S. Bureau of Reclamation at Boulder City, Nev., now is electrician with the Bethlehem Shipbuilding Corporation, Ltd., San Francisco, Calif.

L. J. Richards (A'34) formerly cost accountant with the East Bay Municipal Utility District, Oakland, Calif., now is employed by the Southern Pacific Railway at San Jose as signalman.

R. W. Drushell (A'25, M'36) distribution engineer, The Ohio Public Service Company, Alliance, has been transferred to the Elyria, Ohio, offices of that company.

Kenneth Lannert (A'35) formerly employed by the Sunnen Products Company, St. Louis, Mo., now is associated with the Carter Carburetor Corporation, St. Louis.

J. K. Whistler (A'35) recently was employed as a junior engineer for Black, Sivalls, and Bryson, Oklahoma City, Okla.

C. V. Barnhill (A'36) formerly an engineer with the Rural Electrification Administration at Wichita, Kans., now is with The Research Service, Washington, D. C.

T. H. Mawson (A'29) formerly with the Monsanto Chemical Company at Anniston, Ala., now is with the Commonwealth and Southern Corporation at Birmingham.

R. A. Scholl (A'34) formerly junior engineer with the Public Service Company of Indiana, Connersville, has been made power sales engineer at Indianapolis.

Boyd Stevens (A'33) switchman for the Illinois Bell Telephone Company at Urbana, has been made transmission testing foreman at Danville.

E. S. Henning (A'36) now is junior electrical engineer with the bureau of engineering of the Navy Department, Washington, D. C.

Obituary

Clarence Linus Cory (A'92, M'03, F'13, member for life) professor emeritus of electrical engineering, and formerly dean of the college of mechanics, University of California, Berkeley, died in Berkeley, August 2, 1937. Born September 4, 1872, at Lafayette, Ind., and graduated in mechanical engineering by Purdue University in 1889, Professor Cory entered Cornell University for graduate work under the late Harris J. Ryan, and was awarded the degree of master of mechanical engineering by Cornell in 1891. After teaching electrical engineering at Highland Park College in Des Moines, Iowa, for a short time, he became a member of the faculty of the University of California, serving as assistant professor of electrical engineering from 1892 to 1898, as associate professor from 1898 to 1901, and as professor of electrical engineering and dean of the college of mechanics from 1901 until his retirement from active teaching duties in 1930. In addition to his long service in the field of electrical engineering education, Professor Cory early won a prominent standing on the Pacific Coast as a consulting engineer in connection with many of the early hydroelectric and other power developments in the state of California. He also was identified with several of the early long-distance high-voltage transmission-line projects. Professor Cory was the second chairman of the Institute's San Francisco Section, serving a double term from 1905 to 1907. Later (1914–19) he was an active member of the Institute's committee on economics of electric service.

Harvey Lester Harris (A'18, M'30) president of the Automatic Electric Company, Chicago, Ill., died August 10, 1937. Mr. Harris was born at Presque Isle, Me., on August 21, 1879, and was continuously in the telephone constructing, operating, and allied manufacturing business, starting as night operator for a telephone company in Ohio in 1894. In 1907 he joined the Dean Electric Company, Elyria, Ohio, as switchboard engineer, after being employed in various capacities by several telephone companies. He remained with this company and its successors until 1917, by which time he was sales engineer for the Stromberg Carlson Telephone Manufacturing Company, Rochester, N. Y. In that year Mr. Harris became general manager of the Kansas City Telephone Company and later vice-president and general manager of the Consolidated Telephone Company, Kansas City, Mo., part of the interests of Theodore Gary and Company. Since 1924 he had been executive in general charge of Theodore Gary and Company's manufacturing interests, which include Automatic Electric Company, American Electric Company, Inc., and other companies in England, Belgium, Canada, Australia, and Japan as well as in the United States, serving as director or officer. Mr. Harris was the holder of several patents in telephony. He was a member of the board of governors of the National Electrical Manufacturers Association, and a member of the Western Society of Engineers.

Frank Daniel Burr (A'07, M'20) consulting power engineer, Los Angeles, Calif., was killed in an automobile accident in that city on June 30, 1937. He was born at Frederica, Del., on February 28, 1872, and received the degree of bachelor of science in electrical engineering from the University of Nebraska in 1902. For a year he was employed as electrician in coal mines at Red Lodge, Mont., and then from 1903 to 1907 was employed by the Missouri River

Power Company. For the next 2 years Mr. Burr was with the Colorado Power Company, then during 1909–10 engaged in irrigation engineering work with the Arnold Company for the Denver Reservoir and Irrigation Company and the Southern Colorado Irrigation Company. In 1910 he became power salesman for the Denver Gas and Electric Light Company at Denver, Colo., and 2 years later was made power engineer. He was made commercial representative in 1920, a position which he held until 1927, when he became power sales engineer for the Southwestern Public Service Company at Amarillo, Texas. Two years later he joined the Southern California Edison Company at Ventura as power specialist. For the past several years he had conducted a consulting practice as power engineer.

Samuel Ernest McMillan Henderson (A'09, M'12, F'14, past vice-president) central station engineer, Canadian General Electric Company, Ltd., Toronto, Ont., died September 2, 1937. Born at London, Ont., September 28, 1879, Mr. Henderson received his technical education at Toronto University, graduating in 1900 with the degree of bachelor of science in electrical engineering. Upon graduation he entered the drafting department in the switchboard division of the General Electric Company at Schenectady, N. Y., and shortly was promoted to the switchboard engineering department. In 1906 he took charge of the estimating division, and 3 years later was given full responsibility for the design and manufacture of 110,000/13,200-volt switchboards for the Hydro-Electric Power Commission of Ontario. In 1910 he joined the Canadian General Electric Company at Peterboro as engineer in charge of estimating, design, and manufacture of switchboards and other apparatus, and later was transferred to Toronto as central station engineer. Mr. Henderson was a member of the AIEE committee on protective devices from 1920 to 1926, and of the membership committee 1923–25 and 1933–34, and was vice-president representing District No. 10 during 1923–25. He was a member and president of the Engineers' Club of Toronto, and had been a member of several other organizations.

Abram Hussey (A'06, M'18) retired electrical engineer, Chester, N. J., died August 19, 1937. He had been superintendent of distribution for the Brooklyn Edison Company, Brooklyn, N. Y., for 21 years prior to his retirement in 1934. Born May 9, 1868, at Lathrop, Mo., Mr. Hussey entered electrical work as a wireman for the Western Electric Company at Chicago, Ill., in 1892. Two years later he went to Rutland, Vt., as chief electrician of the Marble City Electric Company, later the Rutland City Electric Company. In 1898 he entered the service of the Cataract Power and Conduit Company at Buffalo, N. Y., and the following year was made general foreman; during his service of 8 years with the company the plant grew from a connected load of 2,000 horsepower to 70,000 horsepower. From 1906 to 1913 he was employed by the New York Central Railroad; first until 1909, with charge of all transmission facilities in the electrified zone, and then in charge of construction and maintenance of all transmission facilities during extension of electrification to more than 150 miles of track. In 1913 he accepted the position of superintendent of distribution with the Edison Electric Illuminating Company of Brooklyn (now the Brooklyn Edison Company), where he had charge of engineering, construction, and operation of the transmission and distribution facilities.

Luther Wilson Copeland (A'35) assistant manager, lubrication engineering department, Wadhams Oil Company, Milwaukee, Wis., died August 26, 1937. Mr. Copeland was born at Huntington, Ark., on August 21, 1901, and received the degree of bachelor of science in electrical engineering from Georgia Institute of Technology in 1926. For a few months following graduation he was employed by the Fort Smith Light and Traction Company at Fort Smith, Ark., then for 4 years was employed by the Sinclair Refining Company at Detroit, Mich., and Atlanta, Ga., in various capacities. In 1930 he joined the Vacuum Oil Company, which later was merged with the Wadhams Oil Company, as assistant sales manager of the industrial oil department, which position he held at the time of his death. Mr. Copeland was an active member of the Milwaukee Section of the Institute, and at the last annual meeting of the Section was elected a director for the term beginning August 1. He was chairman of the entertainment committee for the 1937 summer convention held at Milwaukee in June.

Edgar Davis Edmonston (A'02, M'07, member for life) general superintendent of the Consolidated Gas Electric Light and Power Company of Baltimore, Baltimore, Md., died August 29, 1937. He was born at Washington, D. C., October 23, 1876, and was graduated from Lehigh University in 1898 with the degree of electrical engineer. He then obtained employment with the United States Electric Lighting Company, Washington, for a year, resigning to join the Westinghouse Electric & Manufacturing Company at East Pittsburgh, Pa. In 1900, Mr. Edmonston became electrical engineer for the Lackawanna Steel Company, which was building a large electrically equipped plant at Buffalo, N. Y., and directed the electrical engineering and construction work until he resigned in 1904. In 1905 he accepted the position of chief engineer of the American Construction Company at New Orleans, La., building a complete commercial power and lighting system in that city. Since 1908 he had been with the Consolidated Electric Light and Power Company of Baltimore, which he joined as superintendent of construction, and of which he had been general superintendent since 1911.

Maurice Coster (A'95, M'96, F'12, member for life) retired vice-president of the Westinghouse Electric International Company died at his residence in Magog, Que., Can., on August 31, 1937. Mr. Coster was born in the Netherlands on August 4, 1856, and was graduated from Stevens Institute of Technology, Hoboken, N. J., in 1877 with the degree of mechanical engineer. For a time he was in British Guiana, S. A., as a consulting mechancial engineer, and in 1888 he became associated with the Westinghouse Electric & Manufacturing Company as an engineer, later being transferred to the commercial department. He was sent to Paris, France, as manager of the Societe Anonyme Westinghouse, and returned to the United States in 1905. In 1919, with the formation of the Westinghouse Electric International Company, Mr. Coster became vice-president, and was appointed senior vice-president in 1922, a position which he held until his retirement in 1930. He served on the Institute's board of examiners during 1914–15. Mr. Coster was one of the original 8 founders of the American Manufacturers Export Association, one of the first 50 members of the National Foreign Trade Council, and one of the 24 incorporators of India House.

Arthur Townsend (A'05, M'31) chief inspector, Saskatchewan Power Commission, Regina, Sask., Canada, died on August 18, 1937. Mr. Townsend was born January 7, 1875, at Southampton, England, and attended Goldsmith Technical Institute in London. Between 1891 and 1901 he was employed by various companies in England, and then he entered the electrical testing department of the British Thomson Houston Company at London. He was transferred to the technical staff at Rugby in 1903, and left the company 3 years later to move to Canada, where he installed, owned, and operated the town plant at Milestone, Sask., until 1927. In 1928 he designed and built radio station CHWC at Pilot Butte, and since 1929 had been chief inspector for the Saskatchewan Power Commission.

Paul A. Callis (A'34) estimating engineer, Louisville Gas & Electric Company, Louisville, Ky., died May 11, 1937. He was born at Rosedale, Ind., December 14, 1900, and had been employed by the company since he was graduated from Purdue University in 1923 with the degree of bachelor of science in electrical engineering. He began as an estimator in the electric distribution and construction department, and since 1930 had been in charge of estimating in a supervisory capacity. During this time he aided in the development of a "unit cost" system of estimating, and in compiling drawings used as standard construction by the company.

Maurice Barrere (A'24) consulting engineer, Schneider and Company, Paris, France, died early in August 1937. He was born at Lourdes, France, July 28, 1891, and received his technical education at Ecole Centrale de Paris and Ecole Superieure d' Electricite. Since 1919 he had been an instructor in electrical engineering at Ecole Centrale de Paris, and in 1921 had become connected with Schneider and Company. He was a chevalier of the Legion of Honor, and had received the Croix de Guerre and the Military Cross of England.

Membership

Recommended for Transfer

The Board of Examiners, at its meeting on September 16, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Hitchcock, H. W., chief engineer, Southern California Telephone Company, Los Angeles, Calif.
McEachron, K. B., research engineer, General Electric Company, Pittsfield, Mass.

2 to Grade of Fellow

To Grade of Member

Allen, C. S., design engineer, General Electric Company, Fort Wayne, Ind.
Banes, C. Raymond, electrical research engineer, Long Island Lighting Company, New York, N. Y.
Bryant, W. L., electrical engineer, Imperial Irrigation District, Imperial, Calif.
Cornelius, H. A., designing engineer, Public Service Company of Northern Illinois, Chicago.
Davis, C. L., patent department, Radio Corporation of America, Washington, D. C.
Ehrensperger, C., engineer, Brown Boveri Company, Inc., Baden, Switzerland.
Fowler, C. V., toll transmission engineer, The Pacific Telephone and Telegraph Company, San Francisco, Calif.
Gear, R. B., field engineer, Commonwealth Edison Company, Chicago, Ill.
Goodrich, J. L., electrical engineer, in care of Thomas H. Allen, Memphis, Tenn.
Hallar, K. E. V., assistant operating and maintenance engineer, Husqvarna Vapenfabriks, Huskvarna, Sweden.
Hanson, D. H., section engineer, General Electric Company, Fort Wayne, Ind.
Huntsberger, J. D., battery service engineer, Philco Radio and Television Corporation, Philadelphia, Pa.
Kilbourne, C. E., designing engineer, General Electric Company, Schenectady, N. Y.
Kilgore, L. A., design engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Knoderer, C. L., technical employee, American Telephone and Telegraph Company, New York, N. Y.
Larason, G. E., extension engineer, Oklahoma Gas and Electric Company, Oklahoma City.
Mason, R. C., research engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Payne, C. C., control engineer, central electricity board, Mid-East England area, Leeds, England.
Rawls, J. A., transmission engineer, Virginia Electric and Power Company, Richmond.
Swingle, R. H., patent attorney, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Wetherill, L., electrical engineer, General Electric Company, Pittsfield, Mass.

21 to Grade of Member

Applications for Membership

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before October 31, 1937 or December 31, 1937, if the applicant resides outside of the United States or Canada.

Andrews, P. R., Tennessee Valley Authority, Wilson Dam, Ala.
Archibald, C. G., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Barker, C. J. (Member), Consolidated Edison Company of New York, Inc., New York, N. Y.
Barr, J. R. (Member), General Electric Company, Pittsfield, Mass.
Becker, H. E., Westinghouse Electric & Manufacturing Company, San Francisco, Calif.
Bisson, A. J. (Member), Consolidated Edison Company of New York, Inc., New York, N. Y.
Boldt, W. F., Century Electric Company, St. Louis, Mo.
Bolton, F. D., Canadian General Electric Co., Vancouver, B. C., Canada.
Bottonari, S. A., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Brown, C. B., McCollum Laboratories, Houston, Texas.
Cattolica, J. L., Pacific Gas and Electric Company, San Francisco, Calif.
Chamberlin, J. H., Acme Electric and Manufacturing Company, Cleveland, Ohio.
Clement, P. E., Tennessee Valley Authority, Joe Wheeler Dam, Ala.
Cosentine, L. G. (Member), Wisconsin Gas and Electric Company, Fort Atkinson, Wis.
Criley, W. (Member), Rochester Telephone Corp., Rochester, N. Y.
Daugherty, C. A. (Member), Post Office Box 582, Coral Gables, Fla.
Delo, H. F., Western Electric Company, Kearny, N. J.
Edwards, P. F., Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa.
Elam, R. D., Tennessee Valley Authority, Wilson Dam, Ala.
Farmer, E. B., Electrolux Inc., New York, N. Y.
Fremo, E. C., San Diego Consolidated Gas and Electric Company, San Diego, Calif.
Garris, C. R., General Electric Company, Pittsfield, Mass.
Grethel, B. W., Public Utilities, City of San Francisco, San Francisco, Calif.
Guice, F. J. (Member), Memphis Power and Light Company, Memphis, Tenn.
Harkins, M. A., University of Tennessee, Knoxville.
Haupt, L. M., Jr., A. & M. College, College Station, Texas.
Heath, E. A., Kansas Gas & Electric Co., Wichita, Kansas.
Kelley, W. A. (Member), E. D. Jones & Sons Co., Pittsfield, Mass.
Lyons, S. E., Wilson Dam, Ala.
Mangold, A. O., Northwestern Electric Co., Portland, Oregon.
Mattison, M., Harza Engineering Company, Columbus, Nebraska.
McCarthy, E. T., Alta Electric and Mechanical Company, San Francisco, Calif.
Meinhardt, P. W., Union Electric Company of Missouri, St. Louis.
Olson, O. F., New York and Queens Electric Light and Power Company, Flushing, N. Y.
Painter, J. C., 425 Mason Street, San Francisco, Calif.
Park, C. A., Jr., Tennessee Valley Authority, Wilson Dam, Ala.
Reifsnyder, G. C., Bell Telephone Company of Pennsylvania, Allentown.
Renzi, S. E., United Shipyard Inc., Staten Island, N. Y.
Rodhouse, T. E., General Electric Company, Pittsfield, Mass.
Rodnite, F. A., Public Service Electric and Gas Company, Newark, N. J.
Ruppert, R. B., 629 Franklin Avenue, Columbus, Ohio.
Seitz, F. W., 100–112 Seeboth St., Milwaukee, Wis.
Sims, J. B., Carbide & Carbon Chemicals Corp., South Charleston, W. Va.
Smart, D. L., Detroit Edison Company, Detroit, Mich.
Smith, C. D., Ohio Edison Co., Akron, Ohio.
Strandberg, H. V. (Member), City of Seattle, Light Dept., Seattle, Wash.
Tilyou, I. B. (Member), Cooper Wire Engineering Association, Washington, D. C.
Wade, J. R., Wilson Dam, Ala.
Walker, C. D., Bell Telephone Laboratories, New York, N. Y.
Wasserman, C., Consolidated Gas Electric Light and Power Company, Baltimore, Md.
Whitaker, H. B., Underwriters' Laboratories, Inc., Chicago, Ill.
White, W. C., Northeastern University, Boston, Mass.
Wilcox, H. M. (Member), Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Williams, E. A., Jr., General Electric Company, Philadelphia, Pa.
Williamson, C. A., General Electric Co., Wichita, Kans.
Wohlgemuth, M. J. (Fellow) Westinghouse Electric & Manufacturing Company, Detroit, Michigan.

56 Domestic

Foreign

Bobal, L. (Member), Bata Shoe Company, Inc., Zlin, Czechoslovakia.
Chandler, C. E., Manning & Co. Ltd., Bridgetown, Barbados, B. W. I.
Coomar, H. N., Allgemeine Electricitata-Gesellshaft, Berlin, Germany.
Fenwick, W. (Member), Victoria Falls and Transvaal Power Company, Ltd., Germiston, Transvaal, South Africa.
Sarda, B. D. (Member), Hoshiarpur Electric Supply Company, Punjab, India.
Srinivasan, R., Tinnevelly Tuticorin Electric Supply Company, Brahmin Colony, Tuticorin, India.

6 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Charlton, H. C., 4827 Wilson Avenue, Montreal, Que., Canada.
Evans, Maldwyn F., Canadian Comstock Company, Ltd., Toronto, Ont., Canada.
Fassett, Frank C., 100 Seward Ave., Detroit, Mich.
Gregory, G. A., 1217 Jefferson Street, Olympia, Wash.
Hall, John R., 1464 S. 74th St., West Allis, Wis.
Handy, Lee, 525 W. 113th Ave., Vancouver, B. C., Can.
Hardy, John E., 1741 Pennsylvania Avenue, Denver, Colo.
Herr, Melvin D., South 228 Lincoln St., Spokane, Wash.
Jones, K. B., Trumbull Electric Manufacturing Company, Inc., Ludlow, Ky.
Kirk, W. C., 216 E. 22nd St., Owensboro, Ky.
Koziol, Roman Joseph, 174 Farmington Ave., Hartford, Conn.
Macomber, George S., Federal Power Commission, Washington, D. C.
Matthews, Robert W., 42 St. Stephen St., Boston, Mass.
Roberts, Fred A., 2010 West Michigan Street, Indianapolis, Ind.
Sikofsky, George L., 1206 East New York Avenue Brooklyn, N. Y.

15 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

La FATIGUE des MÉTAUX. By R. Cazaud and L. Persoz. Paris, Dunod, 1937. 190 p., illus., 10x7 in., paper, 75 frs.; bound, 95 frs. Analyzes the principal studies of the fatigue of metals and discusses theories, methods of testing, fatigue limits, the factors that affect fatigue, and the resistance of welded and riveted joints.

BEIHEFTE zum GESUNDHEITS-INGENIEUR, Reihe 1, Heft 36. Die heiztechnischen Neuanlagen des Städtischen Krankenhauses Bad Cannstatt, by H. Wolfer. Munich and Berlin, R. Oldenbourg, 1937. 24 p., illus., 13x9 in., paper, 4.80 rm. Describes the power plant of a large German hospital and reports the results of an operating test.

Der ULTRASCHALL. By L. Bergmann. Berlin, VDI-Verlag, 1937. 230 p., illus., 8x6 in., cloth, 18.50 rm. An account of the present state of supersonics, with emphasis upon the scientific and technical uses of supersonic waves.

YEAR BOOK on COAL MINE MECHANIZATION. Washington, D. C., American Mining Congress, 1936. 362 p., illus., 9x6 in., lea., $2.00. Contains extracts from the reports of various district committees and papers presented at the 1936 convention.

DIESEL ENGINES. By P. E. Biggar. Toronto and New York, Macmillan Co., 1936, 165 p., illus., 9x6 in., cloth, $3.25. Condensed information in the Diesel field covering many particular points and the probable future development of the Diesel type.

MACHINE DESIGN. By P. H. Hyland and J. B. Kommers. 2 ed. New York and London, McGraw-Hill Book Co., 1937. 598 p., illus., 9x6 in., cloth, $4.50. A comprehensive elementary textbook on machine design, arranged to be studied simultaneously with mechanics of materials courses.

TEXTBOOK of THERMODYNAMICS. By P. S. Epstein. New York, John Wiley & Sons, 1937. 406 p., illus., 10x6 in., cloth, $5.00. Thermodynamics is treated from the physicist's point of view, and mainly as apart from statistical mechanics.

(The) SCIENCE of VALUATION and DEPRECIATION. By E. B. Kurtz. New York, Ronald Press Co., 1937. 221 p., illus., 9x6 in., cloth, $4.50. Offers scientific solutions, based on life experience tables, to basic problems in valuation and depreciation estimating and accounting.

Industrial Notes

Arc Welding Forges Ahead.—True to the predictions that were made for it a decade ago, the electric arc welding process has been making tremendous strides in extending its fields of usefulness. The growth in volume in the past five years is shown by the NEMA reports of electric welding wire consumption, from 18.8 millions of pounds in 1932 to 111 millions of pounds in 1936. It is thought in some quarters that there will be recorded a further 50 per cent increase when the total for 1937 is known. That this progress is not all due to the general revival of industrial activity is shown by the steady increase in volume of consumption in the early thirties, before any real revival had started. A more graphic proof is the increasing amount of electrodes being used for each ingot ton of steel poured. In 1932 the figure was 1.4 lbs. of electrode for each ingot ton; in 1936 this figure had reached 2.4 pounds, an increase of 71 per cent.

Electric Appliance Sales Mount.—Retail sales of electric household washers in the first seven months of 1937 amounted to $80,531,874. Machines shipped in this period totalled over one million and their average retail price was $73.39. Ironer shipments for the same period totalled 109,270, compared to 102,988 for the same months of 1936. Vacuum cleaner sales aggregated 1,083,170 during the period, a total which was not reached until October last year. According to the Air Conditioning Manufacturers' Association, sales of air conditioning equipment of its members to the end of July amounted to $68,306,175, which was 37 per cent higher than the volume for all of last year.

Cutler-Hammer Appointments.—A new district office in New Orleans, was opened recently by Cutler-Hammer Inc., with Joseph Gardberg in charge. W. E. Ragsdale has been appointed manager of the Dallas office.

Allegheny Steel Appointment.—Charles H. McKnight has been appointed special sales representative by the Allegheny Steel Co., of Brackenridge, Pa. Since 1912 he was in the employ of the General Electric Co. During the past few years he devoted his time to special cost reduction activities.

American Steel & Wire Promotion.—John May has been elected vice-president in charge of sales of the American Steel & Wire Co., a subsidiary of the U. S. Steel Corp., according to a recent announcement by C. F. Blackmer, president of the wire company. Mr. May has been connected with the company since 1909.

G-E Employees' Service Records.—More than 40 per cent of the employees of the General Electric Company have worked with the company for 10 or more years, according to a recent survey. Those employed more than 5 years number 42,875 and those with 10 or more years of service 32,019. 53 employees have been with the company 45 or more years; more than 200 for 40 years or more; more than 1000 for 35 or more years; 11,705 have worked 20 or more years and 19,773 have been employed 15 or more years.

Westinghouse Appointments.—R. R. Davis, formerly apparatus advertising manager of the Westinghouse Electric & Mfg. Co., has been appointed assistant to the general advertising manager, according to a recent announcement by S. D. Mahan, general advertising manager. J. M. McKibbin, Jr., associated with the company since 1922, has been appointed apparatus advertising and sales promotion manager. Walter Thompson, formerly Eastern sales manager of the radiotron division, R.C.A. Mfg. Co., is now director of utility sales for the Westinghouse merchandising division at Mansfield, Ohio. Angus G. Scott, formerly superintendent of power distribution for Cleveland Railways, has been appointed manager of line material activities at East Pittsburgh.

Trade Literature

Steam Turbine Units.—Bulletin, 28 pp. Describes in considerable detail reaction type turbo-generator units of 1500- to 5000-kw capacity. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Capacitors.—Bulletin 143, 4 pp. Describes a new line of capacitors for power factor correction on electric distribution systems. Cornell-Dubilier Electric Corp., South Plainfield, N. J.

Neutral Clamp and Thimble.—Bulletin 629-H, 2 pp. Describes and gives catalog information on a clamp for grounding the neutral conductor on primary and secondary systems of distribution lines, and on a thimble for dead-ending conductors. Ohio Brass Co., Mansfield, O.

Time Switches.—Catalog. Describes Sauter synchronous and electrically-wound time switches. Types for all time switch applications are listed. R. W. Cramer & Co., Inc., 67 Irving Place, New York.

A-C Generators.—Bulletin 1158-A, 8 pp. Describes a-c bracket bearing type generators, built in standard ratings from 30 to 1000 kva, suitable for coupled service to high speed steam or internal combustion engines. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Suspension Insulator Tests.—Bulletin 623-H, 8 pp. Describes tests of dynamic characteristics of cap-pin insulators; explains what factors influence insulator life, and shows how test data are used in correlating insulator design with field performance. Ohio Brass Co., Mansfield, O.

Vibration Elimination.—Bulletin, 16 pp., "Eliminating Vibration Losses." Describes the application of various methods and materials, such as cork, rubber, etc., for eliminating vibration in the operation of many types of heavy machinery. Korfund Co., Inc., Long Island City, N. Y.

Transformers.—Bulletin GEA 2206C, 4 pp. Describes rural-line distribution transformers in ratings of 1 and 3 kva, which meet the need for inexpensive units designed for application to lines of 13,200 Y volts and below, where a solidly grounded common neutral is used for both high-voltage and low-voltage circuits. General Electric Co., Schenectady, N. Y.

New Constant Level Oiler.—Bulletin. Describes a new line of inexpensive constant level oilers for automatically maintaining an accurate level of oil in ring and ball bearings of motors, line shafts, pumps, and other machinery having oil wells. Trico Fuse Mfg. Co., Milwaukee, Wis.

Arc Welder.—Folder, "The Characteristics of a Modern Arc Welder." Includes volt-ampere curve analysis for general welding, heavy welding and light-gauge welding; describes single-current control, self-excitation and other features in the design and construction of the Hansen Smootharc welding generators. Harnischfeger Corp., 4400 W. National Ave., Milwaukee, Wis.

Mercury Switches.—Catalog 603, 12 pp. Describes the complete line of Kon-nec-tor mercury switches. Full-size illustrations of the twelve common types of mercury-to-mercury and mercury-to-metal switches are included, as well as a table giving the capacity and electrical specifications of each type. A section is devoted to desirable applications of mercury switches. General Electric Vapor Lamp Co., Hoboken, N. J.

Watthour Meters.—A series of bound, loose-leaf bulletins. Bulletin No. GEA-615E, 4 pp., General Information and Index to Contents. No. GEA-2668, 16 pp., Single-Phase, Type I-20. No. GEA-2669, 12 pp., Two-Element, Types V-2 and V-3. No. GEA-1046A, 8 pp., Polyphase, Types D-14 and D-15. No. GEA-1093B, 8 pp., Switchboard A-C Meters, Types IS-8, DS-19, DS-20, DS-21 and DS-23. No. GEA-2670, D-C Meters, 8 pp. No. GEA-1350A, 4 pp., Portable Standards. No. GEA-2671, 12 pp., Accessories and Supplies, describes protective cases, autotransformers, jewels, tool kits, etc. General Electric Co., Schenectady, N. Y.

Modified Schering Bridge.—Catalog E-54 (2), 8 pp. Describes a modified form of Schering bridge for determining the characteristics of samples of both liquid and solid dielectrics. High voltage is applied only to the test samples and to the standard air capacitor. A method of compensation for residual capacitance is used which enables results to be calculated from simple equations. In the case of low power factors, the result is read directly. Capacitances ranging from 40 mmf to 0.020 mf and power factors from 0.0001 to 0.70 can be accurately determined. The bridge is intended for use on 60-cycle circuits and the standard air capacitor and sample holders listed are rated at 10 kv. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.